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AN INTRODUCTION TO THE SCIENCE OF RADIO-ACTIVITY

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BY

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WITH ILLUSTRATIONS

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To

CLEMENT L. WRAGGE, Esq., F.R.G.S., F.R. Met. Soc.

TO WHOSE FRIENDSHIP AND ENCOURAGEMENT

THE AUTHOR IS MUCH INDEBTED.

PREFACE

In the following pages I have endeavoured to give a concise and popular account of the properties of the radio-active elements and the theoretical conceptions which are introduced by the study of radio-active phenomena. This work, as its title indicates, does not claim to be more than an introduction to the subject, and no attempt has been made at exhaustive treatment. Following what has appeared to me to be the most lucid method of presentation, I have divided the subject into three parts: descriptive, theoretical, and practical; the last being added in the hope that the comparatively simple experiments described may be of interest to those wishing to investigate for themselves some of the remarkable properties of the radio-active elements.

Frequent reference has been made to Professor Rutherford's treatise, and I am indebted to this valuable work for several numerical determinations. I also wish to express my thanks to Mr. F. H. Glew for the radiographs illustrating reversal by radium rays and secondary radiation.

CHARLES W. RAFFETY.

Purley,
Surrey,
August 29, 1908.

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PART I

I

1. Introductory Note.—In connection with the penetrating rays discovered by Prof. Röntgen, generally known as the X Rays, it was observed by investigators with the early types of tubes that the glass opposite the kathode fluoresced brightly when the tube was in action. It was from this brightly glowing area that the penetrating radiation appeared to proceed, and the question was raised as to whether the emission of a penetrating type of radiation might not be a characteristic of phosphorescent and fluorescent bodies. It was in the endeavour to answer this question that the science of radio-activity may be said to have its beginning. The science is now but twelve years old, yet it may truly be stated that it has effected almost a revolution in our conceptions of atomic physics, and the advance of knowledge in this time has been marvellous.

In the year 1896, a year ever to be remembered in the history of science, Prof. Henri Becquerel discovered the property of radio-activity. Prof. Becquerel was conducting some experiments with certain fluorescent and phosphorescent chemical compounds, in order to test their effect on a photographic plate and determine whether any penetrating form of radiation was emitted.

The method employed was to enclose a photographic plate in an opaque covering, such as a black or brown paper envelope, and lay a quantity of the substance to be tested outside, the compound being exposed to daylight in order to excite fluorescence. One of the compounds tested was a salt of the element *uranium*. Development showed a distinct action; the plate was clearly "fogged." On one occasion, however, the exposure to daylight was omitted, and shortly afterwards the plate was developed in the usual way, *with the result that the plate was still found to be "fogged."* Here was a fact of first importance, and Prof. Becquerel was not slow to see its significance. He repeated the experiment again, taking most exact care that the uranium salt was never exposed to daylight, obtaining, as he hoped, the same unmistakable result; the plate *was* affected, and in that slight darkening of the film lay a secret which was destined to startle the scientific world and reveal a new property of matter. But as yet it was not clear whether the observed property was peculiar to this particular compound or a distinguishing characteristic of one of its elementary constituents.

Again, was it a property depending on the property of fluorescence or not? The question was easily investigated. Prof. Becquerel performed similar experiments with compounds of uranium which were *non*-fluorescent, and it soon became clear that the property of spontaneously emitting a penetrating type of radiation which could traverse substances quite opaque to ordinary light was a property belonging to the *element* uranium, and *quite independent of its condition of chemical combination.* The action appeared to be dependent only on the amount of the element contained in the compound used; metallic uranium being, therefore, more active than its compounds.

Shortly after these significant experiments, Madame Curie undertook the investigation of the subject. Uranium is derived chiefly from the mineral *pitchblende*, in which it is found in the form of a black oxide. The ore is mined principally at Joachimsthal in Bohemia, and it was the pitchblende derived from this locality that Mme. Curie tested together with other uranium-bearing ores. It was now that a wonderfully interesting result was obtained. Good samples of pitchblende contain about 70 to 75 per cent. of uranium oxide, together with compounds of several other elements in varying quantities. An examination of the ore revealed the fact that it possessed an activity from three to four times as great as that of uranium. It was evident that pitchblende must contain some other substance of greater radiating power than uranium, yet a careful examination of the other constituents failed to reveal that any of these elements possessed an activity capable of producing the observed result. Indeed, it seemed clear that the ore must contain some unknown element in very minute quantities—quantities so small as to escape detection by any ordinary chemical analysis—and that this element must possess an activity correspondingly intense. It was with the intention of isolating this unknown element that Mme. Curie commenced the laborious treatment of the residue remaining after the extraction of the uranium from the crude ore, a large quantity of which had been placed at her disposal by the Austrian Government.

The inactive elements were gradually eliminated by chemical treatment and the products tested at varying stages. It was found that the unknown element always remained associated with barium, to which it appeared to be chemically allied; indeed, the barium obtained was

very radio-active, and it was found impossible, by purely chemical means, to carry the work of separation any further. So closely was the active element associated with barium, that the only means of isolating it was to take advantage of a slight difference of solubility shown to exist between the new element and the corresponding barium salt. This process is known as fractional crystallisation. The *first* crystals to form from the solution of active barium were found to be more active than the remainder and, by repeating the process several times, removing on each occasion the first crystals to form, a very small quantity of salt was obtained from which the barium was almost entirely removed.

The ray-emitting power possessed by this minute quantity of the new element was astonishing, being estimated at about 1,800,000 times the activity of an equal quantity of uranium. Mme. Curie, by a happy choice, called the new element "*radium*." The forms in which radium is extracted are nearly always the chloride and bromide salts; the pure element has not yet been isolated, and, whenever radium is mentioned, it must always be understood that one of its compounds is intended unless specially stated to the contrary. In the later stages of her work, Mme. Curie received the assistance of her husband Prof. Curie, and together they carried on the tedious process of fractional crystallisation. It was while endeavouring to isolate radium that Mme. Curie extracted another element, which was named *polonium*, in honour of her native Poland. This element will be mentioned later.

The "Becquerel Rays" of uranium had meanwhile attracted the attention of many investigators. Early

photographic experiments revealed the fact that substances were apparently opaque to the rays in proportion to their density and independently of their chemical properties; moreover, the rays appeared to be spontaneously and continuously given out by the element uranium under all circumstances, and to be absolutely invariable in intensity. Prof. Becquerel made special experiments to test this point, not only screening the uranium compound from all light, but also protecting it from all external influences by enclosure in a thick metal case. It very soon became evident that the radiation was complex in character, and the study of the experimental investigations on this subject, as well as the theoretical conceptions to which they have led, forms one of the most interesting chapters in the history of science.

Like the rays given out from an X-ray tube, the rays emitted by the radio-active elements are able to render the air through which they pass a conductor of electricity. This property enables accurate investigations to be made concerning the intensity of the radiation, and was used by Mme. Curie and others in testing the various products resulting from the treatment of active ores.

As soon as it was evident that the power of continually emitting an unknown form of radiation was an inherent property of the element uranium, careful tests were made of most of the other known elements to see if there were any among them possessing such a hitherto unsuspected property. One only gave positive results, this was *thorium,* which showed an activity barely as great as that of uranium. Of previously known elements, therefore, only uranium and thorium appeared to possess the property of radio-activity, and this to such a small extent that both these elements had been under investigation

for years without any such property having been discovered. To the scientist, however, it is not the magnitude of the effects produced which determines the importance of a new discovery, but the nature of the phenomena involved, and thus it was recognised that such a property of matter was a thing beyond all comprehension, almost beyond belief in the light of previous knowledge. With the isolation of radium with an activity something like 1,800,000 times as intense as that of uranium, the marvel became most strongly emphasised.

It is not proposed to give detailed accounts of the vast amount of experimental work, both qualitative and quantitative, which has been done in the investigation of the radio-active elements. Where such information is desired, the exhaustive treatises by original investigators must be consulted; all that is aimed at is a concise and simple introduction to a subject which is one of great importance and equally great fascination.

The radio-active elements appeared to be a contradiction to the known laws of physics and one which, in the case of the extreme activity of radium, seemed particularly emphatic. Here was an element, or at least a substance having all the distinguishing characteristics of an element, which was not only giving out energy in the form of radiation in considerable quantity, but also without the slightest sign of exhaustion or any indication of its receiving energy from any possible external source. In addition to this, not the slightest diminution of weight or sign of chemical or physical change could be detected in specimens kept under careful observation for a considerable period, although all this time an intense radiation was being emitted. All this was wonderful indeed, and demanded explanation—an explanation which must, of

necessity, modify fundamental conceptions. Energy can be obtained from chemical processes and combinations, but here was the emission of energy without any such chemical process, without any evident supply of energy, and even without any apparent loss or change. Yet all this while work was being done continuously and incessantly by the tiny quantity of radium compound, a quantity so small as to appear out of all proportion to the effects it produced. In 1903 another remarkable fact was announced by Prof. Curie and M. Laborde—this was that a radium compound maintained itself at a higher temperature than its surroundings. This elevation of temperature is not very marked with the very minute quantities of radium usually available for experiment, but it is beyond question, and readily shown with suitable apparatus.

The quantity of radium in pitchblende is almost inconceivably minute, although different varieties of the mineral show marked differences of activity. Cornish pitchblende has an activity much lower than that obtained from the Joachimsthal district. The proportion of radium found in average samples is stated as being of the order of one ten-millionth per cent.; but such estimates are necessarily approximate. Only a few grains of impure radium salt containing a large excess of barium are obtained from about a ton or so of pitchblende residue, and this is further reduced to a few milligrams during the final stages of purification. Ten milligrams of pure radium bromide or other compound may be considered a fairly large quantity, and comparatively few experimentalists have even this amount at their disposal. The activity of radium, however, is so wonderfully intense, that for very many purposes of investigation small quantities of the impure salts are all that is necessary.

The processes by which the properties of the radio-elements are investigated are marvellously delicate, especially the electrical method which has been most extensively employed, and was used by Mme. Curie in her examination of the majority of the known elements. If any of the ordinary chemical elements possessed an activity only one-hundredth that of uranium, it would probably not have escaped detection by this method. The subject of the possible activity of the chemical elements is one of considerable importance, and further reference will be made to it in the sections dealing with theoretical considerations of the phenomena involved.

2. Spectrum of Radium.—On the assumption that radium is an element, it should show a distinct and characteristic spectrum. In order to obtain such evidence of the true nature of radium, Prof. and Mme. Curie submitted some specimens of radium chloride for spectroscopic examination. With salts containing a large excess of barium, the spectrum of this latter element was, of course, predominant, but some new lines in the ultra-violet also appeared. With compounds of greater purity, a new and characteristic spectrum was observed and the barium lines became much fainter, only one or two of the strongest remaining when a nearly pure salt was examined, while the new spectrum was clear and distinct. Such evidence as this confirmed the idea that radium was really a new element and not a modified form of barium.

3. Chemical Properties of Radium.—The close resemblance of radium to barium as regards chemical affinity, places it in Group II of the periodic law of the elements, and in the sub-group containing calcium, strontium and barium, elements which are quite devoid of any appreciable radio-activity. In this respect it will

be seen that there is nothing to distinguish radium from the normal chemical elements.

Attempts to determine the atomic weight of radium were made by Mme. Curie with quantities of salts of gradually increasing purity. With a salt containing a very large excess of barium the atomic weight determined was equal to that of barium, namely, 137·5. With specimens of increasing purity the values obtained were higher, and the final value, determined with a practically pure salt, was 225. Other investigators have, from spectroscopic observations, deduced a value of 258. This determination is not only widely different from that found by Mme. Curie, but would make radium possessed of an atomic weight higher than that of any known element. Dr. Marshall Watts, however, has deduced, also from spectroscopic observations, a value in close agreement with that found by Mme. Curie. There are other reasons, which will be mentioned later, which seem to render an atomic weight greater than that of uranium very improbable. Quite recently Mme. Curie has redetermined the atomic weight of radium by the chemical process, using a very carefully purified specimen. This new determination, which gives a value slightly in excess of 226, may be regarded as the best determination we possess, and one which, in all probability, is very accurate. Assuming this value for the atomic weight of radium, we see that there are only two elements with higher values namely, uranium 239, and thorium 232; and also that radium comes last in Group II, and in series 12 with the two last-mentioned elements.

4. Polonium.—This was the first radio-active substance extracted from pitchblende by Mme. Curie. As regards its chemical properties it is very closely allied to bismuth

and it has been found impossible to isolate it from this element. Preparations of bismuth have been obtained containing sufficient polonium to exhibit a very high activity indeed. Spectroscopic examinations of such preparations have failed to give any sure indications of a new spectrum, so that it must be concluded that, even in these very active specimens, polonium must exist in excessively minute quantities, and that its activity must be intrinsically intense. The activity of such preparations of bismuth containing polonium is not constant, for Mme. Curie noticed a very perceptible decline in the activity in the course of a few months.

5. Actinium.—M. Debierne, while working at the uranium residues, succeeded in detecting another new radio-active body which closely resembled thorium in its chemical affinity, although it was vastly more active. It was named by its discoverer "*actinium*," but subsequently the name "emanium" was also applied to this substance. As in the case of polonium, actinium has never been completely isolated or obtained sufficiently pure to exhibit a characteristic spectrum.

II

6. Rays emitted by Radium.—So far as the purely *chemical* properties of radium are concerned, there is nothing to distinguish its behaviour from that of a normal element. It is when the *physical* properties of radium are considered that the marvel becomes most impressive, for phenomena are encountered hitherto unsuspected and unimagined, and on a scale of intensity which appears enormous in comparison with the amount of matter involved in their manifestation.

It should first be clearly stated that the rays emitted by the radio-active elements are absolutely invisible and can only be made evident and investigated by their effects. On account of the high activity of radium and the consequent intensity of the rays, effects are observed which are not so evident with the elements of feebler radio-active properties. The difference is, however, one of degree rather than of kind, and this will be clear when the theory of radio-activity is discussed.

The first point to notice is the one mentioned above namely, that the absorption of the rays by matter is a property depending upon density and independent of the nature and chemical properties of the absorbing medium. In this there is a marked similarity to the X rays, but the rays from radium are characterised by a power of penetration which is extraordinary. The most penetrating radiation which can be obtained from an X-ray tube is

stopped by a thin sheet of metal—indeed, except in very thin sheets, all the ordinary metals but aluminium are opaque to the rays—yet the rays emitted from a very small quantity of a pure radium salt can easily be detected after having passed through a centimetre of lead.

A few milligrams are sufficient to demonstrate this power of penetration and give a very distinct impression on a photographic plate after the rays have passed through very considerable thicknesses of various metals. A sealed glass tube containing this small quantity of radium will produce excellent radiographs of coins or keys etc. in a purse with an exposure of an hour or so, by merely supporting the tube for the requisite time a few inches above the plate with the purse laid upon it.

Like the X rays, the rays from radium cause bright fluorescence in certain minerals and crystals and various chemical compounds. Diamonds and some other precious stones glow in the dark on the approach of a tube containing a small quantity of radium. Barium-platinocyanide is particularly sensitive to radium rays, and crystals of this compound will glow brightly even when the radium is held several inches away, or after the rays have passed through a considerable thickness of wood or even several coins. The mineral willemite is also sensitive to the rays and so are certain others in varying degrees. In some compounds there is also a distinct phosphorescence for a short time after the removal of the radium.

The electrical effects of radium rays are very evident, as the rays cause an intense ionisation of the air through which they pass. The mere approach of a tube containing a few milligrams of radium will cause a rapid fall of the leaves of a charged electroscope, and even if the tube be enclosed in an outer metal cylinder, the movement of the

leaves is still quite perceptible provided the metal is not very thick. A piece of silk ribbon, folded in two and electrified by friction so that the two lengths repel one another, will be speedily discharged if held above the tube, and an electrified silk tassel will likewise quickly collapse.

Radium rays can cause certain chemical changes. Oxygen appears to take the form of ozone in the presence of radium; while radium salts in solution in water slowly decompose it, liberating its component gases, oxygen and hydrogen. Glass tubes in which radium is sealed become discoloured in the course of time. With impure salts of a not very high activity, the colour assumed is a beautiful mauve or amethyst tint, and several weeks or even months are required before it becomes at all decided. With salts of greater purity, the discolouration is more rapid and is generally brown, growing darker with time until it is almost black. Some cases of change produced by radium rays appear to be rather of the nature of physical modifications.

The physiological effects of radium rays are most marked, and great care is necessary in handling and experimenting with radium on account of the harm resulting from excessive exposure to the rays. Many investigators suffered from ignorance of this in the early days before the properties of the rays were understood. Prof. Curie, having exposed his arm to the rays for some time, suffered from an intense and painful inflammation as the result. The carrying of tubes containing radium in the pocket is attended with risk and possibly serious results, unless precautions are taken to shield the body from the rays by enclosing the tubes in thick lead. The action is analogous to that of the X rays, but it is only

when a fairly large quantity is employed that there is much necessity for protection unless the exposure is prolonged.

7. Appearance and Luminosity of Radium Salts.—There is nothing in the appearance of radium compounds that is in any way remarkable, nothing to give a hint of their marvellous physical properties. The forms most generally met with are the chloride and bromide salts, both of which appear as whitish crystals which, in the case of the bromide, darken with time and assume a brownish tint. Viewed in a darkened room, these radium compounds show a faint luminosity. This light must not be confused in any way with the rays referred to above; it is entirely a secondary effect which is much more pronounced with the impure salts than with the pure. Some specimens of impure salts show a very marked luminosity and it is in all cases necessary for the salt to be dry for the maximum effect to be observed. The action is apparently analogous to the fluorescence produced in certain substances referred to above, as the rays, which are emitted by the radium in all directions, also strike inwards, causing the substance of the compound to glow.

III

8. Nature of the Rays emitted by the Radio-active Elements.—In order to understand the nature of the radiation in question, it is best to first briefly consider the other forms of invisible radiation known to scientists before Prof. Becquerel discovered the radio-activity of the element uranium. The classical experimental investigations of Sir William Crookes on the discharge of electricity through high vacua may be said to have prepared the way for the correct interpretation of the wonderful phenomena of radio-activity. The rays which were found to proceed from the kathode of an exhausted tube, called "radiant-matter" by their discoverer, and afterwards known as the kathode rays, have been investigated very thoroughly by Prof. J. J. Thomson and other physicists. The results have been not only to confirm to the full the idea that these rays are particulate in character, but also to show that these particles are not atoms but bodies roughly one-thousandth the mass of the hydrogen atom, which is the lightest atom known to science. Prof. J. J. Thomson called these particles "corpuscles," and has demonstrated that they are always invariable in character no matter whether the gas in the bulb in which they are generated be elementary or compound, or whatever metal may be employed to form the kathode plate. From this it seemed evident that these corpuscles were common constituents of all atoms from

which, under suitable conditions, they could be detached. It was also discovered that the corpuscle carried a negative charge of electricity which was of invariable amount whatever their source, and that this charge was equal to that carried by the hydrogen ion in electrolysis. Prof. Thomson was enabled to determine the velocity attained by these corpuscles within the vacuum tube by means of the deflection suffered by the rays in traversing a magnetic or electrostatic field, and from this he was also able to find both the charge carried by a corpuscle and its mass.

The determination of these facts concerning the corpuscles was a veritable triumph both from the theoretical

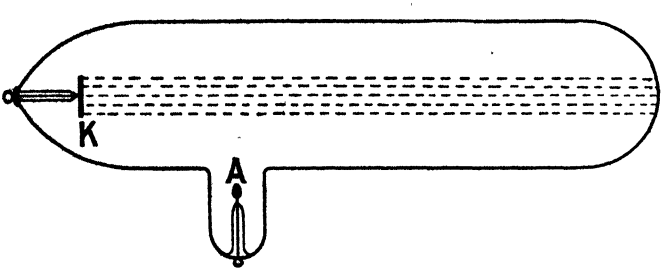

FIG. 1.—Kathode Ray Tube.
K = kathode plate. A = anode.

point of view, and as a wonderfully delicate piece of experimental work, and the importance of these investigations cannot be overestimated, for by means of them we have become acquainted with bodies little more than one-thousandth of the mass of the lightest known atom, and which can travel with an almost inconceivable velocity. The velocity of these particulate kathode rays is about 25,000 miles per second, although this is variable within

fairly wide limits according to circumstances, the most important being the electric potential of the kathode; indeed, the velocity is directly and almost entirely dependent on the kathode potential, but this, in turn, is dependent on the degree of exhaustion of the tube.[1]

It appeared evident that the kathode rays could not penetrate the glass side of the tube, as there was no trace of them outside. The energy of motion of the corpuscles was evidently absorbed by the glass, which showed a bright spot of fluorescence where the rays impinged upon it. As the rays always travel at right angles to the surface of the kathode whence they originate, they form a parallel beam when proceeding from a kathode composed of a smooth flat-plate. By having the kathode formed of a concave surface, however, they can be brought to a "focus," and at such a point of convergence, the heating effects produced by the stopping of the corpuscles is very evident.

Lenard was the first to use a tube with a "window" of thin aluminium through which the beam of corpuscles passed readily, and their effect outside the tube could be investigated. One of the most important effects produced by these "Lenard rays" (as the kathode stream is called when it has passed out of the tube) is an intense ionisation of the air. Sir W. Crookes had demonstrated, by some of the most beautiful experiments imaginable, the wonderful power of the kathode rays to cause fluorescence and phosphorescence in various minerals and chemical compounds. A large number of minerals and crystals and a

[1] Velocity is generally of the order of 2×10^9 cms. per second, but under exceptional conditions a velocity of about 10^{10} cms. per second is possible.

wide range of chemical compounds exhibit marvellously beautiful hues when enclosed within the exhausted bulb and subjected to the bombardment of the kathode rays. "Lenard rays" also show this power of causing fluorescence and phosphorescence, and the effects are obviously far more easy to investigate.

It will be remembered that Prof. Röntgen first discovered that the fluorescing glass opposite to the kathode in a vacuum tube was the source of an unsuspected form of radiation which could penetrate objects quite opaque to ordinary light, and affect strongly a photographic plate; this being the discovery of the now well-known X rays. It was, however, some time before the method of development of this radiation was recognised. It appeared that wherever and whenever kathode rays were stopped by impact with solids, X rays were produced, and it was afterwards discovered that the impact of the corpuscles on dense solids, like the heavy metals, produced a far more powerful emission of X rays than when the stoppage was allowed to take place by the glass side of the tube. Besides their wonderful power of penetration and photographic action, the X rays are also able to produce brilliant fluorescent and phosphorescent effects, although they themselves are quite invisible. It was found possible to produce "shadow-pictures" of objects on fluorescent screens, but in the early types of tubes the definition was bad owing to the radiation proceeding from a considerable area. The great advance in the production of X-ray tubes was the insertion of a platinum anti-kathode in the path of the rays brought to a "focus" on its surface by a concave kathode. This gives intense radiation from a small area and the definition is vastly improved.

It soon became clear that the X rays, whatever their

real nature, were not composed of particulate bodies carrying a negative electric charge like corpuscles, for they cannot be deviated in the strongest magnetic fields, and their wonderful power to penetrate matter seemed also against this view although, as will be seen later, corpuscles travelling at enormously high velocities possess a marvellously great power of penetration. It appeared, rather,

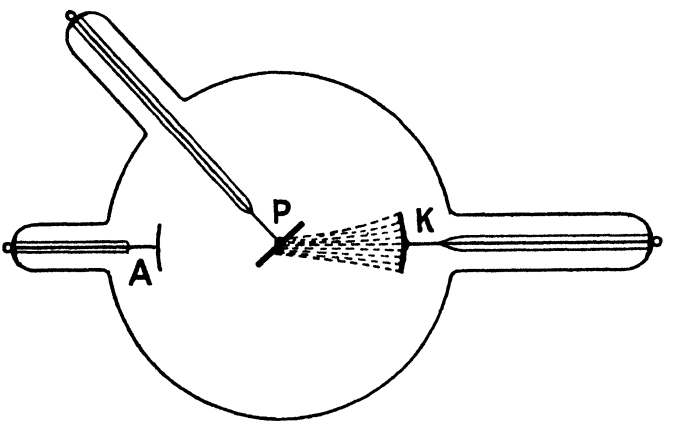

FIG. 2.—X-ray Focus Tube.
K = kathode. A = anode. P = anti-kathode.

that the X rays were some sort of etheric disturbance set up by the sudden stoppage of the flying corpuscles. Theoretical considerations point to the conclusion that whenever an electric charge in steady, uniform motion is stopped, a pulse is communicated to the surrounding ether, and it seemed probable that the impact of the corpuscles on the platinum anti-kathode set up a very penetrating etheric disturbance. That this form of radiation must be of a special and peculiar description,

quite unlike light or ultra-violet rays, was evident from the failure of all attempts to reflect or refract the wave-pulses, and at the present time the mystery of the X rays can hardly be said to be fully solved.

In connection with the phenomena of vacuum tube discharges, another type of rays has been investigated by Prof. Thomson. Knowing that the atoms of the residual gas in the tube are broken down into ions in the process of conveying an electric discharge, it seemed reasonable to look for a stream of positively charged carriers (*i.e.* positive ions) projected from the anode. Such "positive rays" have been found, although for their proper investigation a specially arranged tube is necessary. Unlike the kathode rays which travel in straight lines independent of the position of the anode terminal, the path followed by the positive rays from the anode appears to be modified by the position of the kathode, to which they tend to travel. By placing the anode plate opposite a kathode having an aperture through the middle of it, the "positive rays" pass through, and the stream can be investigated on the other side of the kathode. Owing to the fact that these positive rays pass through a channel in the kathode plate they are known as the "canal rays," although "anode rays" would, perhaps, be a better term.

As to the nature of these canal rays, there can be little doubt that in them we have a stream of positive ions. These ions are the atoms of the residual gas which have lost a negative corpuscle and, the original atom being electrically neutral, they have thus a positive charge equal and complementary to the charge of the corpuscles. As the mass of the positive ion of hydrogen is practically the same as that of the neutral atom, while the charge is no greater than that carried by the negative corpuscle, the velocity

attained by the canal rays under a given electrical potential is not, comparatively speaking, great.

We are thus acquainted with three types of radiation,

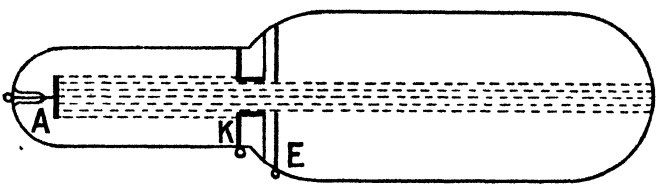

FIG. 3.—"Canal" Ray Tube.
A = anode. K = perforated kathode. E = earthed screen.

two of them being particulate and the third apparently a form of etheric disturbance. These are—

(i) Canal or positive rays;
(ii) Kathode rays;
(iii) X rays.

In investigating the nature of the rays spontaneously emitted by radium and the other radio-active elements, we meet with forms of radiation very closely analogous to the rays mentioned above.

The process of gaseous discharge may be briefly described as follows. In the residual gas contained in the exhausted tube, a very few ions are always to be found among the swiftly moving gas molecules. When the kathode plate becomes charged, any positive ions near are at once attracted and rush towards it. Just before they reach the kathode, their velocity may be great enough to ionise the gas molecules through which they pass, thus making more ions and, the negative ions being violently repelled, start away to ionise the gas further from the

kathode. The function of the positive ions produced from either source when they reach the close proximity of the kathode, is to drag or pull the negative corpuscles out of it, thus tending to relieve it of its charge. When the corpuscles are free of the metal of the kathode, the violent repulsion which they experience causes them to fly away in straight lines, giving rise to the kathode stream. Their velocity is so great that the position of the anode has little or no effect on them unless the vacuum is very low, which means that they exhaust their velocity in collisions with the gas molecules, and the electrostatic pull of the positive electrode is thus felt.

Directly there is a tendency to lower the kathode potential by conducting away the corpuscles, more corpuscles are supplied along the conductor which connects the kathode with the source of current supply. The circuit is completed in low vacua by the direct rush of negative ions (*i.e.* corpuscles) to the anode, and in high vacua there is an indirect flow.

We are led to consider negative corpuscles as constituents of all atoms for, in addition to the kathode stream of the vacuum tube, corpuscles are liberated from gases at a very high temperature, incandescent metals and carbon, metals under the radiation of ultra-violet light, and they can be generated in any gas by the passage of rays capable of causing ionisation. We see that a gas atom, although electrically neutral, is capable of losing a small fraction of its mass in the form of the negative corpuscle, which thus leaves the remainder of the atom with a positive charge or, in other words, a positive ion. On the withdrawal of the agency by which this forcible splitting up of the atom takes place, the ions will again recombine, but there is an appreciable interval before this

recombination can be effected, and during this time the gas retains its conducting power. The negative corpuscle of the vacuum tube and the negative ion of ionised gases are identical in character, and to both the word "*electron*" is now more usually applied, and this term will be used in the following chapters.

In all electrical phenomena, the electron appears to be the active agent, and the "electron theory" is a new statement and interpretation of electrical science and the allied branches of physics.

The deflection of the kathode stream by an electrostatic field is demonstrated by using a tube as shown in the diagram. Prof. J. J. Thomson employed a similar apparatus in the determination of the properties of the electrons projected from the kathode plate, using, at the same time, a magnetic field acting at right angles to the electrostatic. The kathode stream tends to describe a circle in passing through a magnetic field of uniform intensity, the plane of the circle being at right angles to the lines of force. The electrostatic field can be made to act either with, or against, the magnetic by the polarity imparted to the plates and, with a proper adjustment of potential, the two opposed fields will neutralise each other, the deflection again being zero. The electrostatic action is one of attraction and repulsion, the kathode stream describing a curved path like that followed by a body projected at right angles to the earth's surface. In another form of tube used in the determination of the velocity of the electrons, a zinc plate, negatively electrified, is exposed to a beam of ultra-violet light. Under these conditions a stream of corpuscles is projected from the plate and, after passing through an aperture in a screen connected to earth, falls on a plate to which an

electrometer is attached which shows a deflection by reason of the charge acquired. On the application of the magnetic field, the corpuscular stream is deflected and, by falling on a second plate in the side of the tube, produces a deflection in a second electrometer in connection with it. The radius of the curve followed by the corpuscles under the influence of the magnetic field is

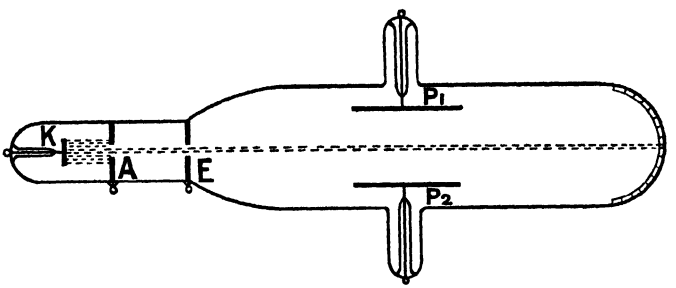

FIG. 4.—Tube for showing the Electrostatic Deviation of the Kathode Rays.

K = kathode. A = anode. E = earthed screen. P_1, P_2' = charging plates.

determined by the relative positions of the two electrometer plates. By this method the velocity of the corpuscles can be calculated from a knowledge of the values of (i) the radius of the circle which they tend to describe, (ii) the intensity of the magnetic field necessary to produce that deflection, and (iii) the electric potential of the zinc plate from which they originate. This is thus expressed by

$$v = \frac{2V}{rH}$$

where V = potential, r = radius of circle, and H = magnetic field.

As already mentioned, the velocity attained by corpuscles is variable within wide limits depending on conditions, the highest velocity which is produced in vacuum tubes being probably that found in the case of a "hard" X-ray tube.

In order to understand corpuscles it is necessary to

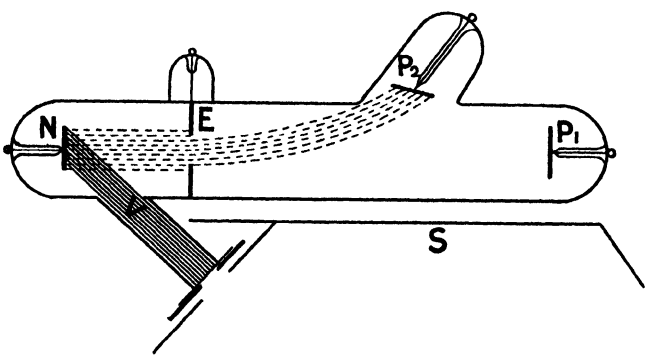

FIG. 5.—Tube for showing the Magnetic Deflection of the Electrons projected from a negatively charged Zinc Plate under the influence of Ultra-violet Light.

N = negatively charged zinc plate. V = beam of ultra-violet light. E = earthed plate (perforated). P_1, P_2 = plates connected with electrometers. S = screen.

know, not only the various velocities with which they can be endowed, but also their mass and the value of the negative charge they carry. The ratio which the charge bears to the mass, *i.e.* the value of $\frac{e}{m}$, is of the highest importance. The various experimental methods by which this has been determined need not be given here; suffice to say that the value is always constant, no matter from

what source the corpuscles may come. In the experiment quoted it would be expressed by

$$\frac{2V}{(rH)^2}$$

The determination of the electrical charge carried by a corpuscle offers, both theoretically and experimentally, a very formidable problem. It has, however, been successfully attempted, the method employed being an application of a curious property of ions, both negative and positive, namely, that they become nuclei about which atoms and molecules can collect. Ions produced in air saturated with water vapour can cause a condensation in the form of a mist of droplets, each ion becoming a centre of condensation. It is not experimentally possible to directly count the drops, but the number may be arrived at by determining the volume of water deposited and dividing it by the volume of a drop. This last factor can be found by observing the time taken by the drops to fall, as the time is dependent on their size. The total electrification divided by the number of droplets would give the charge carried by the corpuscles on the assumption that the number of droplets represented the same number of corpuscles. A complicating factor, however, is found in the fact that positive ions likewise provide centres of condensation, although not as readily as negative.

The negative corpuscle or electron is thus invariable, whatever its source. It has a mass about $\frac{1}{1000}$th that of the lightest known atom, more exactly $\frac{1}{770}$th of the hydrogen atom, and appears to be a fundamental unit common to all atoms.

NOTE.—The above formulæ are quoted from "The New Knowledge," by Prof. R. K. Duncan, in which a popular account of the method will be found.

IV

9. Methods of Investigation.—The photographic method of investigating the rays emitted by the radio-active elements, although very sensitive and useful for certain qualitative tests, is somewhat limited in application and unsuitable for many kinds of experimental work, especially of an accurate and quantitative nature. There are many ways in which a photographic plate may become affected, and it is almost impossible to ensure absolute uniformity of conditions of development for the purposes of comparative tests. It thus becomes necessary to find some method by which reliable measurements of activities can be obtained, and such a method is available in the property possessed by all the radio-active elements of rendering air or other gas in their immediate vicinity capable of conducting an electric charge by the process of ionisation.

Any electrified body within the range of ionisation will thus lose its charge with a speed proportional to the degree of ionisation, and the discharge of a gold-leaf electroscope is a method of observing and measuring ionisation which has been very largely employed. Until the discovery of radio-activity, the uses of the electroscope were limited almost entirely to demonstrating certain phenomena of electrostatics, but in the last few years it has, in a somewhat modified form, assumed a very great importance as an instrument of research. In the modern form,

one of the gold leaves is replaced by a metal plate, to which the leaf is attached.

The rate of fall of the leaf is observed through a small window in the case by a short-focus telescope with a micrometer eyepiece, the angle through which the leaf falls in a certain time being taken as a measurement of the ionisation. This ionisation is produced between two metal discs, one connected electrically with the insulated rod of the electroscope, while the other is connected to earth and placed a few centimetres below the first. The active material to be tested is placed in a uniform layer over the lower disc, the ionisation produced by the rays causing the discharge of the upper disc, and hence a lowering of potential indicated by the diminished angle between the leaf and the fixed plate. The electrical method is capable of a degree of refinement and sensitiveness which is almost incredible. By this means the most minute traces of active matter can be readily detected; indeed, quantities so infinitesimal that the most refined spectroscope would utterly fail to give the faintest indication of their existence.

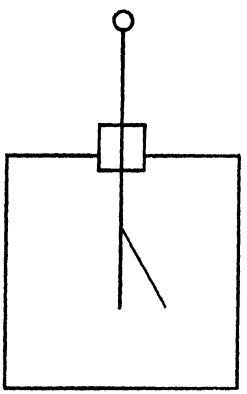

FIG. 6.—Modern form of Electroscope.

Although the discharge between the external metal plates is the usual method of investigation, especially with substances which are not very active, another modification of the electroscope is found in an instrument in which the plate and attached leaf are completely insulated within the case, charging connection being made by a moveable metal

contact passing out through an insulating medium in the top of the case. The ionisation takes place within the chamber, the rays being admitted through a small window of mica or thin aluminium. In such an instrument the case itself is metal and connected to earth.

Although air in its normal state is a nearly perfect insulator, it is necessary to accurately determine the rate of fall of the leaf before testing for very feeble radiation, as there is always some slight leak owing to dust particles, imperfect insulation, or even a very slight natural ionisation in the air. This variable source of error must always be remembered and allowed for.

There is a third method by which the rays of the radio-active elements can be demonstrated; this is by means of the fluorescent properties of certain minerals and chemical compounds which give out visible light when the invisible rays fall upon them, in much the same way as when they are exposed to the X rays. This property of causing fluorescence is only clearly evident, in the majority of cases, when the comparatively intense radiation from radium salts of high activity is employed, but, as will be shown later, the fluorescopic method of investigation is also capable of an astonishing degree of sensitiveness under proper experimental conditions.

10. Complexity of the Rays.—A very minute quantity of a radium compound contained in a cavity in a block of lead, and brought close to a charged electroscope, will cause a rapid fall of the leaves. If the aperture be covered with a thin piece of mica, aluminium, or card, etc., the fall of the leaves will be very much slower. The addition of a second piece of mica will not, however, again affect the rate of fall to any appreciable extent, showing that a portion of the radiation emitted is

very easily stopped, and that it is also responsible for a considerable fraction of the total ionisation. The inability of a second layer of mica to appreciably reduce the ionisation further, shows that the remainder of the radiation emitted must be of a quite different and much more penetrating character. In the case of light passing through a piece of neutral tinted glass, there is a further absorption on the addition of a second piece similar to the first, owing to the fact that the light is homogeneous. Clearly, then, a considerable portion of the ionising power of radium depends on a form of radiation which suffers easy absorption by matter, and all effects produced on photographic plates enveloped in black paper envelopes, or by any specimens of radium enclosed in glass tubes, must be due to that more penetrating form of radiation which appeared unaffected by the addition of successive layers of mica.

11. The Deviation of the Rays in a Magnetic Field.—The properties of radium rays suggest strongly a resemblance to kathode and X rays, and this resemblance is greatly emphasised by their behaviour in passing through a magnetic field.

The experiment of the magnetic deviation was early performed by Prof. Becquerel. A quantity of radium was placed in a groove in a lead block, which was then placed on a photographic plate, the aperture being, of course, upwards.

The plate was shielded from all direct action by the considerable thickness of lead between it and the radium, the emerging rays forming a beam directed away from the plate. The arrangement was then inserted between the pole-pieces of a powerful electro-magnetic and a strong field maintained for a considerable time. After the reversal

of the polarity for a like period, the plate was developed and gave unmistakable proof of strong action on each side of the position occupied by the radium. It is easy to show that these rays which are deviated in a magnetic field constitute the more penetrating portion of the total radiation emitted, for the action is not affected appreciably by covering the plate or the aperture in the lead block with mica or paper. It is certain that these deviable rays must consist of particles, and that these particles must be electrically charged. A similarity to the kathode stream of a vacuum tube is strongly suggested, and is emphasised by the fact that the direction of deviation proves that the charge is negative. We have, then, become aware of two distinct types of radiation, the first having great power of ionisation but possessed of a feeble penetrating power, and the second also capable of ionising gases but endowed with a very considerable power of penetration and showing the properties of the electronic kathode stream when placed in a magnetic field. It soon became evident that radium emitted a third type of radiation also, for a considerable action is observable some distance above the lead block, although it may be traversed by a very powerful magnetic field and covered by a thin piece of aluminium to stop the most easily absorbed rays. Prof. Becquerel was able to prove its existence by arranging a photographic plate vertically above the radium and allowing the rays to graze its surface, the magnetic field being applied as before. Development showed the tracks of two distinct streams, the one curved, the other appearing absolutely unaffected, and gave clear evidence of three distinct types of radiation which are simultaneously emitted by radium. These three varieties are distinguished by the first three letters of the Greek alphabet;

the rays which suffer easy absorption by matter are known as the α (alpha) rays, those which are deviated in a magnetic field are called the β (beta) rays, and the rays which show no such deviation are known as the γ (gamma) rays.

The powerful ionising properties possessed by the α rays, taken in consideration with the fact that they are so very easily absorbed by matter, apparently without regard to its particular nature, renders it almost certain that these rays also are particulate in character although, at first, all attempts to deviate them magnetically failed, which seemed to point to the conclusion that if particulate they, at least, carried no charge.

Later attempts, however, with magnetic fields of the greatest possible intensity have proved beyond doubt that, not only are the α rays particulate, but also that the particles are positively charged; this being proved by the direction of deviation, which is contrary to that observed with the β rays.

The γ rays have remained absolutely undeviable, and in their properties they appear very similar to the X rays, although their power of penetration is enormously greater. The study of the phenomena met with in investigating the discharge of electricity through gases at low pressures, has brought to our knowledge the three types of radiation before mentioned, namely:—

(i) The "canal" or positive rays,
(ii) The "kathode" or negative rays,

both of these being particulate; and

(iii) The X rays.

We have now evidence of three closely similar types which are simultaneously emitted by radium,—

(i) The α rays (positively charged particles);
(ii) The β rays (negatively charged particles);
(iii) The γ rays (like X rays; probably ether pulses).

Does this similarity of properties mean a practical identity of character? In order to answer this question, the order of the velocity of motion of the α and β particles should be known, also their masses and the value of the charges they carry, and here again the magnetic deflection gives the means of solving the problem.

V

12. The α rays.—In the α rays emitted by the radioactive elements, we have the most characteristic and important of the three forms of radiation although, in the earlier stages of investigation, this importance was not fully recognised. The great penetrating power of the β and γ rays from radium, together with their other remarkable properties, caused most of the experimental work to be directed towards the study of these rays, the interest created being greatly stimulated by the discovery that the β rays were deviable in a magnetic field and the implied similarity to the kathode stream of the vacuum tube. All the early attempts to cause an appreciable deflection of the α rays were without effect, no observable deviation being produced by magnetic fields of sufficient strength to cause a very considerable action on the β rays, and it was suggested by experimentalists that they might be secondary rays set up in the active substance by the action of the β rays. Certain observations on the absorption of the rays by matter, however, seemed to point to the conclusion that they consisted of particles projected with great velocity from the substance of the active body, and this view was put forward by Mme. Curie, and also by Sir W. Crookes and certain other physicists. The fact that polonium was found to emit only α rays was sufficient to negative the idea that they were a form of easily absorbed secondary radiation due to the β rays.

13. Magnetic and Electrostatic Deviation.—Prof. Rutherford also concluded in favour of the hypothesis that the α rays were particulate, and undertook their investigation with the aid of very intense magnetic fields. The experimental arrangements were of such a nature as to render the smallest deflection evident. A thin layer of a radium compound was spread over the bottom of a vessel, and a parallel series of narrow slits, formed of metal plates placed close together, was arranged above so that the α rays passed up through the narrow channels between the plates into an ionisation chamber containing an electroscope. Any deflection of the rays produced by the application of a field parallel with the plane of the slits would cause them to fall on the sides of the plates forming the walls of the slits, and the ionisation would be very greatly reduced.

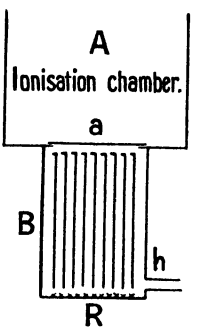

FIG. 7. — Apparatus used by Professor Rutherford in the investigation of the α rays.

A = ionisation chamber. B = sectional view of slit arrangement. a = aluminium foil. h = hydrogen outlet tube. R = active substance.

The experimental apparatus is somewhat complicated in detail and need not be fully described; it may be stated, however, that the gas used was hydrogen, which allows a greater ionisation range for the α rays than air.

That the reduced ionisation observed on the application of the magnetic field was not due solely to the removal of the β rays which were, of course, also completely deviated by the field, was evident from the experiment of covering the apertures of the slits with a piece of mica of sufficient

thickness to completely stop the α rays. The readings of the electroscope leak when the magnetic field was used without the mica screen, and when both were employed together were sufficiently close to render it clear that all but a small fraction of the total α radiation was deviated. Prof. Rutherford was also able to show, by means of specially constructed slits, that the direction of deflection was in the opposite sense to that shown by the β rays, proving that not only do the rays really consist of particles, but also that these particles carry a positive electric charge.

Some idea of the intensity of the magnetic fields necessary to produce an appreciable deviation of the α particles can be gathered from the fact that a field of an intensity sufficient to cause the electrons of the kathode stream to describe circles of 0·1 cm. radius, will only suffice to curve the α particles into an arc of 39 cms. radius.

The magnetic deviation of the α rays from both radium and polonium was also successfully investigated by Prof. Becquerel by means of the photographic method; the image obtained by the deflected rays consisted of a well-defined band, proving that the particles travelled with velocities sufficiently uniform to prevent them from being appreciably spread out in the distance travelled. It was inferred from this that the α particles all travel with the same velocity, but it will be seen later that, in the case of radium, α particles are emitted with varying velocities. The deflection of the α particles has also been investigated in a partial vacuum and by this means their range is greatly increased, the degree of deviation being correspondingly magnified.

The electrostatic deviation of the α rays follows, like

the magnetic, as a theoretical necessity from the fact that they are charged particles, but it is even more delicate of experimental investigation owing to the practical difficulties involved in the apparatus required. The charge of the plates must be considerable to produce an observable deflection, yet there must be no possibility of sparking through the ionised air. In spite of the delicate nature of the experiment, however, it has been performed with considerable success.

With the data given by the magnetic and electrostatic deflections of the rays, it is possible to determine the velocity and the value of $\frac{e}{m}$ of an α particle by a method similar to that employed by Prof. J. J. Thomson in his researches on the kathode rays. The values given by Prof. Rutherford are

$$V = 2{\cdot}5 \times 10^9 \text{ cms. per second}$$

and

$$\frac{e}{m} = 6 \times 10^3$$

Numerous researches as to the nature of the α particle have been made by many investigators, and in these, for the most part, it has been necessary to employ experimental apparatus of a complex description of which details need not be given. There is every reason to suppose that the value of e, that is to say the charge carried by the α particle, is the same as that associated with the hydrogen atom. As the value of $\frac{e}{m}$ is known, the value of m is at once determined. Owing to the many complications and difficulties of the experimental work necessary, the mass of the α particle is not known with any great certainty, but the best determinations

give a mass little greater than 2, the hydrogen atom being taken as unity. Certain evidence, which will be mentioned later, was thought to support the idea that the α particle was an atom of helium. This would give it a mass of 4 as compared with hydrogen, which is not in good agreement with the determination given above. The uncertainties in this case, however, are as yet too great to render a definite decision possible, and in the meantime it is possible to marvel at the phenomena under consideration, for we have knowledge of elements which are possessed of the property of emitting continuously a form of radiation consisting of particles of atomic dimensions which not only carry an electric charge, but are also endowed with an enormously high velocity. It must be remembered that the α particle is not like the electron, it is a body having the mass of an atom—indeed, it is an atom—and that an atom should be endowed with a velocity as high as one-tenth that of light, is a fact which would have been scarcely thought possible before the wonderful properties of the radio-active elements were investigated.

All the five radio-active elements hitherto mentioned, radium, actinium, uranium, thorium, and polonium, the first radio-active substance extracted from the uranium residues by Mme. Curie, emit α rays, and it is in this form of radiation that their activity is most manifest, for the β and γ rays from thorium are excessively feeble, while in the case of polonium these rays are absent altogether.

We learn, then, that the α particle is a body of atomic dimensions with a mass which appears to be intermediate between the atomic weight of hydrogen and that of helium, and which carries a positive electric charge which

is, to the best of our knowledge, the equal and complementary charge to that possessed by the negative electron. The data may be set forth thus:—

The α particle.

Mass = 2·5 (approximately)
Electric charge–positive.

ratio $\frac{e}{m} = 6 \times 10^3$

(Velocity) V = $2{\cdot}5 \times 10^9$ cms. per second
= 15,000 miles per second (approximately).

The mass and the charge carried appear, so far as our present knowledge goes, to be always constant, no matter whether the α particles be emitted from radium or the other radio-elements, but the velocity, as shown by the ionisation range in gases, varies with the nature of the radio-active element in question.

14. Properties of the α rays.—The α radiation from radium is intense, but the power of penetration possessed by the rays is, of course, quite independent of the intensity, for a thickness of a certain medium which is sufficient to stop any one α particle will also be able to stop the whole radiation, whether it be feeble or copious. If, then, it is found that a piece of mica or thin aluminium will completely stop the α radiation from a minute quantity of radium, it is quite certain that it will also completely stop the α rays emitted by a larger quantity, as it is merely a question of the vastly greater number of the α particles, not a difference in velocity and hence of penetrating power.

15. Ionisation Range.—In consequence of the high velocity of an α particle combined with its relatively

large mass, it has considerable kinetic energy $\left(\frac{mv^2}{2}\right)$. It is doubtless owing to this that the α rays possess their great power of ionising gases. The kinetic energy of the particles is exhausted by their collisions with the gas atoms lying in their path, a number of which are broken down into ions in the shock of impact. It is estimated that each α particle (from radium) produces about 86,000 ions before its energy is so far reduced that its power of further ionisation is lost. The range of the α particles naturally varies with the nature and pressure of the gas through which they pass and also with their varying velocities depending on the elements emitting them. As radium emits α particles with varying velocities,[1] there are different ranges of ionisation; none of the particles, however, have an effective ionisation range of more than about 7 centimetres in air at normal atmospheric pressure. The actual path is probably much longer than this, but it is not marked by the formation of ions beyond the limit indicated and hence cannot be directly followed and investigated.

16. Power to penetrate Matter.—As already stated, the power of penetration possessed by the α particles is slight, but this is not surprising when their mass is considered. There is good reason to suppose that even the densest solids must be penetrated to a very slight degree, although it is only when exceedingly thin sections of solids of small density are employed that the α particle retains enough of its kinetic energy to continue to ionise a gas after its emergence on the side remote from the point of impact. An exceedingly thin piece of mica can

[1] The reason of this will be clear when the radio-active products are considered.

be penetrated and ionisation produced on the other side which can be detected by an electroscope. Pieces of aluminium-foil and gold-leaf are also able to allow the particles to pass, but in every case a very little addition to the thickness, such as by adding more leaves over the first, is sufficient to stop all action.

17. Photographic Action.—The α rays do not possess much power of photographic action, the greater part of the effects produced by a radio-active substance being due to the β and γ radiation emitted. The fact that the α rays, by which the activity of the radio-elements is most characterised, should be only slightly active photographically, is one of the disadvantages of this method of testing. In addition to this, the envelope of black paper or similar covering, with which it is often necessary to protect the plate from any light rays or even from any slight phosphorescence exhibited by the substance under investigation, is of sufficient thickness to completely stop these rays. To get the maximum photographic action it is essential that the film of the plate should be exposed without any covering to the α rays, and as close to the active substance as possible, in order to avoid the effects of absorption of the rays by the intervening air. The photographic method, however, has been of great service, especially in preliminary investigations of the activity of mineral ores, and also in studying the magnetic deflection of the α rays.

18. Action of the α rays on Fluorescent Substances.—The α rays exhibit a remarkable power of causing fluorescence in many chemical compounds and also some minerals. The mineral willemite, which is a silicate of zinc, emits a green fluorescence when exposed to fairly intense α radiation, and many diamonds also show a

marked luminosity under similar circumstances. Platinocyanide of barium is affected by the rays, but it does not appear to be very sensitive. The compound which possesses the greatest sensitiveness to the α rays is crystalline zinc sulphide, which glows a very beautiful and vivid green under the action of the α rays from radium.

19. The Spinthariscope.—The fluorescent glow produced in many substances by various forms of radiation such as kathode rays, X rays, ultra-violet light, etc., appears as a diffused and continuous luminosity extending uniformly over the surface, or, in some cases, throughout the volume, of the substance in question. The fluorescence produced in some substances by the α rays, however, is distinguished by a phenomenon of exquisite beauty and interest.

Sir W. Crookes discovered that if a screen coated with crystalline zinc sulphide be exposed to the α radiation from a very minute quantity of radium, it exhibited a wonderful and astonishing appearance, for, although only a faint glow was visible to the unaided eye, the use of a lens magnifying about twenty to thirty diameters showed that this seemingly continuous glow was in reality composed of a large number of scintillating points of greenish-white light. The scintillations have no movement of translation, but come and go in rapid succession, no two appearing to follow one another at the same point on the screen.

It is difficult to liken this beautiful effect to any more familiar sight, but perhaps the best description which has been suggested is that of moonlight reflected from the ripples of a calm sea. To illustrate this property of the α rays, Sir W. Crookes devised a little instrument which he has called the "Spinthariscope." It is formed of a short brass tube with a screen coated with crystalline

zinc sulphide at one end and an observing lens with screw focussing adjustment fitted at the other. A small pointed brass needle is fixed a few millimetres above the screen, and on the side of this nearest to the screen a very minute quantity of radium is deposited by moistening it with a solution of a radium salt. On evaporation an invisible film of the salt remains, and the *a* radiation from this makes itself evident by the scintillations produced on the screen.

The action varies in intensity, of course, with the distance between the radium and the screen, and some forms of the instrument are provided with a means of varying the distance to illustrate this. The marvel is most impressive when it is remembered that the effect is produced and maintained incessantly by a quantity of radium too small to be visible, and that there does not appear to be the slightest loss of activity with the lapse of time.

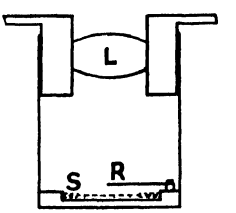

FIG. 8.—Sectional view of Spintharıscope.

L = lens. S = fluorescent screen. R = radium on metal point.

The scintillating appearance of the screen is quite explicable when the particulate nature of the *a* rays is considered, each flash of light corresponding to the impact of one of these atomic particles on the screen. When an *a* particle strikes the surface of the screen, that particular crystalline fragment which is struck immediately flashes with fluorescent light. The theory of this light emission will be discussed later, but it may be remarked that in the scintillations observed we have possibly the only direct evidence of the action of *one individual atom* known to science.

20. Fluorescopic Method of testing for α radiation. —Since the activity of the radio-elements is chiefly characterised by the emission of α particles, and the impact of these projected particles on a screen coated with such a sensitive compound as zinc sulphide is marked by the production of scintillations in the crystals struck, it is clear that a very feeble activity would nevertheless be capable of producing a visible effect, provided that the radiation from a considerable area of the active material could be observed in this way. This is impossible, however, in the spinthariscope, as the view of the screen would be prevented by the interposition of a quantity of active substance great enough to produce the necessary effect. It was Mr. F. Harrison Glew who first demonstrated the great possibilities of the fluorescopic method as a delicate test for α radiation by introducing a transparent screen of glass, one side of which is coated with the fluorescent substance. This is viewed with a lens in the ordinary way, but the active substance is placed *below* the screen, thus enabling the radiation from a considerable area to be readily examined. The active substance is spread out in a layer and the fluorescent screen is laid over it with its sensitive surface next to the active body. The area from which the radiation can be examined is thus only limited by the field of view of the observing lens, and there is the additional advantage of the absence of absorption by air which, by the resistance offered and the consequent reduction of the kinetic energy of the α particles, would reduce the effect to be observed.

The α radiation from pitchblende and uranium oxide is clearly evident by this method, being marked by the production of scintillations on the screen when it is viewed with a lens in a darkened room.

The range of the α particles in gases at various pressures, and the absorption effected by different media, are also capable of being directly investigated with transparent screens.

The power of the α particles to affect a photographic plate, ionise a gas or produce scintillations, appears to cease somewhat abruptly when the velocity is reduced below a certain critical value. This is an important and interesting fact, and the value of this critical velocity seems very nearly the same in the three cases, all scintillations vanishing after a certain thickness of air has been traversed by the rays.

The power of showing the scintillating effect is not confined to zinc sulphide, other compounds also exhibiting the property in varying degrees. Willemite, in the form of a coarse powder, is sometimes nearly as effective, and a screen made of diamond fragments is also capable of showing the action.

21. Kinetic Energy of the α particles.—The high velocity of an α particle combined with a mass which, although exceedingly minute, is nevertheless great in comparison with an electron, is the explanation of the considerable kinetic energy which it possesses. Prof. Rutherford gives it as

$$\frac{1}{2}mV^2 = \frac{1}{2}\frac{m}{e}V^2e = 5{\cdot}9 \times 10^{-6} \text{ ergs.}$$

22. Heat Emission by Radium Compounds.—The fact that a given mass of a radium compound continually maintains itself at a higher temperature than its surroundings has already been mentioned. There can be no doubt that this effect is almost entirely due to the energy of the α particles being converted into heat. Owing to

the fact that the α particles are easily stopped by solid matter, a radium compound may be considered as practically opaque to its own α radiation unless it is spread out in a very thin layer. The importance of the *form* in which such a compound is used when a maximum of α radiation is desired is thus evident, as it is only the α particles emitted at or very near the exposed surface that are able to get clear of the matter around the point from which they are projected. So far as the emission of its radiations is concerned, a radium compound is, of course, uniformly active throughout its mass, but in the case of the α particles much of this activity is not externally evident owing to the stoppage of the particles within the mass of the compound. The energy in such a case is manifested in an elevation of temperature. Even in the case of a relatively large quantity of radium the temperature maintained is only a few degrees above that of its surroundings, but it is very significant. Investigations into the heat emission of radium were made by Prof. Curie and M. Laborde, and their experiments have led them to the conclusion that one gram of pure radium would emit a quantity of heat equal to about 100 gram-calories per hour.

VI

23. The β rays.—The discovery of the β rays emitted by radium has already been mentioned. One of the first observations in connection with these rays was the fact that a magnetic field was capable of modifying the conductivity of the air ionised by the radiation from radium. The sharp curvature of the rays in a strong field would, of course, reduce the ionisation produced at some distance from the radiating substance. The deviation of the β rays was more clearly shown by the work of Prof. Becquerel, who used the photographic method of investigation.

The effect of a magnetic field on the β rays is also readily demonstrated by the fluorescopic method. If a lead tube containing a small quantity of radium be arranged between the poles of an electro-magnet so that a pencil of rays is directed upwards at right angles to the field, and a fluorescent screen placed horizontally above it, a bright spot of light will be seen when the screen is observed in a darkened room. On the application of the field, the spot widens out on one side so that it is no longer clearly defined, but presents an elongated patch of light.

It has been stated that the deviation of the β rays by a magnetic field gave an early proof that these rays are particulate, and the fact that the deflection was in the same sense as that exhibited by the kathode rays showed

that the particles carried a negative charge. It became a matter of importance to determine the nature of the particles, and this is effected in a similar manner to that originally employed for the kathode rays.

24. Magnetic and Electrostatic Deflection.—The investigation of the β particles by means of magnetic and electrostatic fields is not attended with the difficulty experienced in similar experiments with the α rays. The photographic experiments of Prof. Becquerel showed that, assuming the value of $\frac{e}{m}$ to be constant, the particles were emitted with velocities varying over a fairly wide range, for the impression produced on the plate by the deflected rays was not sharply defined but extended into a diffused band or "spectrum." The insertion of thin sheets of platinum and aluminium in the paths described by the rays also pointed to the conclusion that the particles which undergo the greatest deflection are those which suffer the greatest absorption by matter.

The value of the ratio $\frac{e}{m}$ and the velocity of the β particles was worked out by Prof. Becquerel with the aid of both the magnetic and electrostatic methods. The determinations arrived at are—

$$V = 1{\cdot}6 \times 10^{10} \text{ cms. per second}$$

and

$$\frac{e}{m} = 10^7$$

It will be seen that the ratio of the charge to the mass is of the same order as that found for the electrons of the kathode stream, while the average velocity is much

greater. The actual velocities with which the β particles are projected from radium vary from 0·2 to 0·9 the velocity of light, while it has not been possible to impart a velocity in excess of about 10^{10} cms. per second to the electrons expelled from the kathode in a vacuum tube even under the most favourable conditions of experiment, and in all ordinary tubes the velocity is always much less than this.

We are led to regard the β particles emitted by radium as electrons precisely analogous to those forming the kathode rays, but moving with exceptionally high velocities, and the facts become wonderfully significant when it is remembered that this emission is an intrinsic property of the element, being not only continuous but also spontaneous.

25. Ionisation of Gases.—The β rays cause considerable ionisation in any gas through which they pass, although this action is not so marked as with the α rays. The β rays, however, have a very much longer range over which the ionisation is produced, and with a tube containing a few milligrams of a nearly pure radium compound the effects are very striking, but in this case the fact must not be forgotten that the γ rays are present also, and a considerable proportion of the ionisation phenomena is attributable to this cause.

26. Power to penetrate Matter.—Owing to the exceptionally high velocities of the β particles, they have very considerable power of penetration. The absorption effected by matter is approximately proportional to the density of the medium, but, as the rays are possessed of a wide range of velocity, a quantitative determination of their absorption in different media is necessarily complicated.

A sheet of metal or mica just sufficient to completely stop all α radiation leaves the β rays almost unaffected, and ionisation is still produced by the rays after they have penetrated a considerable thickness of metal, due to the enormous velocity of the more swiftly moving electrons. One centimetre of lead is considered to be sufficient to insure that all the β rays shall be absorbed, and this is probably the minimum which could safely be employed in any experiments where the complete elimination of the β radiation is desired.

There is evidence that the direction of motion of the β particles can be altered by their passage through matter so that their emergence is marked by a diffusion of the rays. The significance of this, however, becomes more apparent when the theoretical explanation is considered.

27. Photographic Action.—The photographic action of the β rays is characterised by considerable intensity. This is proved by their effects when deviated away from the accompanying γ radiation by a magnetic field, when a very decided action is produced, marking their path on the photographic plate.

On considering the results arising from the negative acceleration of an electron as exemplified by the impact of the kathode rays on the metallic anti-kathode in a vacuum tube, it seems possible that a part of the observed effect may be due to the secondary radiation set up by the impact of the β particles on the plate. If such a secondary effect is produced, however, it is probably only slight, as the power of glass to stop the β rays is not great.

The experiments of Prof. Becquerel on the deviation of the rays also proved their photographic action after passing through different metals, including platinum.

28. Action of the β rays on Fluorescent Substances.

Like the kathode rays, the β rays produce vivid fluorescence in many substances. Several minerals become brightly luminous, willemite being very sensitive to these rays as well as to the α rays, and glowing with the same greenish hue. Many specimens of diamond also show a distinctive fluorescence, and among various chemical compounds the fluorescence of barium-platino-cyanide is especially vivid. In most cases, however, when the properties of the rays are being investigated, the γ rays are also contributing to the observed effect, and for accurate experiment on the fluorescence excited by the impact of the β rays alone, their isolation in a magnetic field would be necessary.

There is no distinct scintillating effect observable with the β rays, although they are particulate, and their action on zinc sulphide is only marked by the production of a uniform green glow which appears steady. With special precautions, however, a screen of barium-platino-cyanide exhibits a flickering appearance suggestive of a discreet and localised action due to the separate effect of the electrons constituting the rays, but the fluorescence is not marked by any distinctive scintillations.

29. Disintegrating Action on Matter.—Various substances of complex chemical composition, like organic compounds, suffer actual mechanical disintegration after prolonged exposure to radium rays of considerable intensity.

Paper and india-rubber, after having been wrapped round tubes containing relative large quantities of highly active radium compounds, become quite rotten. This action is, of course, distinct from the chemical changes produced in stable compounds by radium rays, but both appear largely due to the β rays. It seems probable that the harmful physiological effects are also attributable to these electronic rays.

30. Uranium, Thorium, and Actinium.—The emission of β rays is also a characteristic of uranium, thorium, and actinium, but not polonium. Like the α radiation from these elements, the β rays emitted are feeble in comparison with the activity of radium, but are essentially the same in nature and consist of electrons endowed with very high velocities.

VII

31. The γ rays.—The third type of radiation emitted by radium has an almost incredible power to penetrate matter. The γ rays appear to be similar to the X rays in their properties, but are endowed with very considerably greater power of penetration than the most penetrating variety of X rays that can be generated from a "hard" tube. A few milligrams of radium bromide are sufficient to show the action of the γ rays by the fluorescence produced on a barium-platino-cyanide screen after the β rays have been completely stopped by the interposition of 1 cm. of lead.

The γ rays can also be investigated by the electrical method, as they produce ions in the gas they traverse. Prof. Rutherford states that the γ radiation from 30 mgs. of radium bromide could be detected by the electroscope after passing through 30 cms. of solid iron. The photographic action of the rays is also intense, and most of the action produced by any radio-active substance appears attributable to the γ radiation emitted.

Fluorescent effects are produced by the γ rays to a marked extent in a wide variety of substances, although there are some cases in which the action appears to be somewhat different to the X rays.

32. Nature of the γ rays.—As regards the absorption of the γ rays by matter, experiment shows that, like the X rays, it is also a question of density, but assuming the

γ rays to be a variety of ether pulsation, it seems impossible to assign a limit to the penetration of the rays. All that can be said definitely is that a certain thickness of lead or other substance effects such an absorption of the rays emitted by a certain given quantity of radium, that the most sensitive methods of detection yet known fail to give any clear indication that any fraction of the radiation passes the absorbing medium. The use of a considerably larger quantity of the active substance, however, will give a decided action through the same medium which previously appeared sufficient to completely absorb the radiation, yet it cannot be concluded from this that the use of a larger quantity of radiating matter produces a different and more penetrating variety of γ radiation. The nature of the radiation must be the same whether the quantity of the radio-active element from which it proceeds is small or great, and, considered in this sense, the power of penetration is independent of the mass of the active substance, and therefore of the total volume of radiation emitted.

As has already been stated, the γ rays are not deviable to the slightest observable extent in the most powerful magnetic fields which can be obtained. This constitutes another close similarity to the X rays, and strengthens the idea that the γ rays must be a variety of etheric disturbance. Some scientists, however, have failed to see in this property any conclusive evidence against the view that the γ rays may be particulate. It is pointed out that the most swiftly moving electrons, as exemplified in the β rays, have very considerable power of penetration and also show that they are more difficult to deviate than the electrons which constitute the kathode rays. It has been argued from this that electrons moving with velocities

very closely approaching the velocity of light itself would exhibit the properties of the γ rays, both as regards power of penetration and behaviour in a magnetic field.

This theory, however, is open to considerable objection. In the first place it must be remembered that even the electrons of the β rays which are endowed with the highest velocities, considerably in excess of one-half the velocity of light, are all easily deviable in a magnetic field, and it seems impossible that, even assuming the γ rays to consist of electrons moving with still higher velocities, there should be no observable effect produced by any magnetic field experimentally obtainable. The power of penetration possessed by the γ rays seems also opposed to such a view, but the most obvious objection, perhaps, is that there is no intermediate type of radiation between the most penetrating variety of β rays and the γ rays. In other words, there is no evidence whatever of the emission of electrons with intermediate velocities which would, in a magnetic field, occupy the gap existing between the curves marking the paths of the β particles and the straight path of those which, according to this theory, constitute the γ rays. There are various reasons why such a sharp discontinuity is improbable. The difficulty is partially removed by assuming the component particles to be uncharged, but such an assumption seems hardly justified, as there is no evidence of the existence of bodies the size of electrons which are electrically neutral.

The theory which has found the widest acceptance is that the γ rays are a form of pulsation of the ether closely analogous to the X rays. It will be remembered that the sudden negative acceleration of an electric charge, as exemplified by the impact of the electrons of the kathode stream on the metal forming the anti-kathode, is capable

of creating an electro-magnetic pulse in the surrounding ether. To account for the electro-magnetic nature of the γ rays, it has been suggested that the β particles experience a negative acceleration by impact with the substance of the radio-active body emitting them, and that this corresponds to the action of the anti-kathode in an X-ray tube, generating a similar kind of radiation. It is a very important fact that γ rays are never emitted by any radio-active element unless there is a simultaneous emission of β rays also, but a brief examination of the explanation given above will suffice to show that, while it may be assumed with considerable justification that the γ rays are etheric pulsations, they cannot be generated in the manner indicated.

The penetration of the radiation from an X-ray tube is dependent on the rate of acceleration experienced by the electrons, and the effectiveness of the tube is much increased by making the anti-kathode of a dense metal like platinum in order that the acceleration should be very sharp, for the velocity of the kathode rays, although great, is not so high as to render this impossible when a sufficiently dense form of matter is employed to effect it.

The case is different with the β rays, however; their power of penetration is considerable with even the densest media, and the substance of a radium compound is a form of matter possessing so small a density that the resistance it offers to the β particles is absolutely inadequate to effect any acceleration capable of producing a penetrating form of radiation, still less γ rays, which are far more penetrating than any radiation which can be obtained from an X-ray tube even under the most favourable conditions. If the γ rays were produced in this way, it would seem that an appreciable variation in the intensity of the

radiation should be obtained with slight modification of the condition of the radium compound. In seeking the theoretical explanation of the γ rays, the possibility of a *positive* electronic acceleration of sufficient rapidity suggests itself. Such an acceleration is also effective in creating an electro-magnetic pulse in the ether, and there is good reason to suppose that the γ rays result, as a secondary effect, from the sudden positive acceleration experienced by the β particles at the moment of emission from the active substance. This question will be further considered when the theoretical explanations of radio-active phenomena are dealt with, but it may be remarked that although this view as to the nature of the γ rays finds support from the majority of physicists at the present time, Prof. Bragg, from considerations of certain phenomena of secondary radiation, has recently advocated the idea that both γ and X rays are mainly particulate, and that the production of ether pulsations, although a necessary effect, is only of minor importance. The question is, strictly speaking, an open one at the present time, but it may be mentioned that, in the absence of conclusive evidence to the contrary, the case in favour of the ether-pulse theory is sufficiently strong to warrant its acceptance, at least, provisionally.

As γ radiation follows as a necessary consequence from the emission of β rays, it is given out by actinium, uranium, and thorium, but in the case of these elements, especially thorium, it is very feeble, and can only be separately detected when comparatively large quantities are employed.

VIII

33. Secondary Radiation.—It is well known that the incidence of X rays on solid objects, especially metals, gives rise to a secondary radiation, which appears very similar in its action to the primary rays, but possesses less power of penetration. The rays emitted by the radio-active elements are likewise capable of setting up secondary radiation, although, except in the case of radium, such radiation is necessarily very feeble. It is on account of this diffused emission of secondary rays that radiographs produced by the radio-active elements lack sharpness of definition. This is especially evident with long exposures and when the objects are metallic.

The nature of this radiation has been made the subject of inquiry by several physicists, and there is now a considerable amount of experimental evidence on the subject. All three forms of radiation given out by radium appear to be able to set up a secondary action, although it is very feeble in the case of the α rays.

The amount of the secondary radiation set up by any given primary radiation varies with the nature of the medium and also with the volume employed, but reaches a maximum for a certain thickness, the value of which varies with different substances. In every case the possibilities of direct action of all primary rays must be carefully avoided by the interposition of a very considerable

thickness of lead between the electroscope or other means of detection and the radio-active substance.

In addition to an extensive use of the electrical method, the photographic plate has also been largely serviceable in the experimental work on the secondary rays. A wide range of substances has been employed as radiators, and the results show that, almost without exception, the secondary rays set up by a given primary radiation increase in intensity with the density of the radiator. Most of the action appears due to the β rays, although there is no doubt that the γ rays also contribute much to the observed result.

34. Effect of Magnetic Field.—The secondary rays have also been made the subject of investigation by means of a magnetic field, the results showing clearly that a considerable part of the radiation consists of the expulsion of electrons with velocities approximately one-half that of light. It should be mentioned that the velocity is deduced from their power of penetration, and it seems probable that there is also an emission of electrons with velocities very much lower than this. The difficulties of experiment, however, make the fuller elucidation of the nature of the secondary rays a complex matter. In addition to the secondary emission of electrons, there appears to be a form of X radiation of small penetrating power which is presumably set up partly by the impact of the primary β rays and partly by the accelerations of the electrons liberated as secondary rays.

It is very important that a clear distinction be made between the *spontaneous* radiation emitted by a radio-active element and the temporary rays which are given out by inactive matter while under the stimulus of incident radiation; one is a natural physical property,

spontaneous and incessant, the other a temporary emission lasting only while the special conditions for its manifestation are present.

The subject of secondary radiation is very important, for the theoretical consideration of the phenomena, although complex, leads to a closer insight into the mysteries of the atom. More recent work on the question points to the conclusion that the intensity of the radiation depends more on the atomic weight of the radiator than on its density.

Apparently no clear evidence has yet been obtained of a form of secondary radiation corresponding to the emission of α particles, although it seems possible that such a form may exist under special conditions.

It should be remarked that the angle of incidence of the primary rays modifies the intensity of the secondary radiation, but the latter is in all cases of a general and scattered description, and it is certain that no part of the effect is due to any form of "reflection" of the primary rays.

The angle which appears most effective for the incidence of the primary rays is about 45°, but the reason for this is obscure.

35. Electrical Effects due to Ionisation.—Owing to the intense ionisation produced by very active specimens of radium salts, the proximity of a tube containing a small quantity of radium will facilitate the passage of an electric spark by reason of the ions supplied. Two spark-gaps arranged in parallel can be so adjusted that the spark just refuses to pass by the one but succeeds in bridging the other. On causing an intense ionisation near the silent spark-gap by the presence of a tube containing a radium compound, the discharge can be produced while it ceases

to pass by the alternative path through the second spark-gap. This effect is best observed with short sparks.

Another interesting property of the rays is the increase in the electrical conductivity of selenium. In this respect the action is not unlike that of light.

36. Electric Charge developed by Radium.—As radium is constantly emitting positively charged atoms in the form of α particles and also negative electrons, any insulated matter absorbing either form of these rays should gradually acquire an electric charge. The great difficulty encountered, however, in any experimental attempt to obtain such a charge, is the discharging action of the ionised air surrounding the body which neutralises the charge as fast as it is accumulated. Various arrangements have been made to obviate this. In an attempt at the direct determination of the charge carried by the β rays, Prof. and Mme. Curie employed a block of lead insulated by being enclosed in solid paraffin and connected by a wire with an electrometer. The α rays were unable to reach the lead, but the β rays were absorbed by it, and hence communicated to it their negative charge, which was shown by the electrometer. The charge increased with time, but was excessively small and only detectable with difficulty after all precautions against ionisation discharge had been taken.

In the case of radium enclosed in a sealed glass tube, all the α rays are stopped by the glass, but the β rays pass through quite readily. Under such circumstances the inner surface of the tube, and also the substance of the radium itself, acquires a positive charge, which gradually increases with time. In the case of a tube containing a quantity of radium of high activity, the charge may become great enough after the lapse of several months to

cause a spark at the moment of opening the tube. For this reason it is advisable, when sealing up permanently any specimens of highly active radium compounds, to supply a means of relieving the electric strain by a platinum wire fused into the glass, as otherwise the charge might, in time, become great enough to fracture the tube.

The property exhibited by radium of acquiring a positive electric charge, owing to the emission of negative electrons in the form of β rays, is demonstrated in a very striking manner by an instrument which is sometimes referred to as the "radium clock." A tube containing a small quantity of radium is supported from a thin glass rod inside a glass bulb exhausted to a high vacuum. Attached to the lower end of the tube are two gold leaves which are in metallic connection with the radium by means of a platinum wire passing through the glass. Two metal plates, connected to earth, are so arranged within the bulb that the gold leaves will touch them when they reach a certain angle of divergence.

As the α particles are all stopped by the tube, the positive charge gradually increases and is communicated to the leaves, which, being both charged with electricity of the same sign, repel one another.[1] The high vacuum in the bulb is necessary in order to prevent the discharge of the leaves by ionisation of the air which would otherwise be contained within it. When the charge reaches a

[1] According to the electron theory, the positive charge does not move in the process of electric conduction, all electric currents consisting of the flow of negative electrons. On this view the correct statement of the action is that the negative electrons in the neutral metal of the leaves flow up to partly neutralise the positive charge acquired by the radium and the internal surface of the tube. This flow of electrons from the leaves causes them to be charged to a positive potential, which is neutralised again by the negative charge derived from earth on contact with the earth plates.

certain value, the leaves touch the earth connections and fall together again. The process is repeated indefinitely, and some idea as to how long the radium is capable of causing such an action will be gathered when the theory of the radiation is discussed, but in the meantime it may

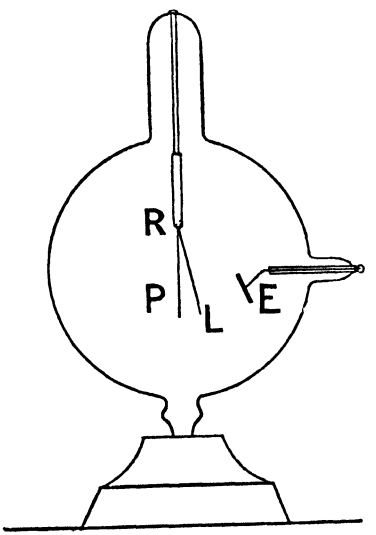

FIG. 9.—Radium "Clock."

Ṙ = radium in tube. P = metal plate. L = leaf. E = earth-connection.

By using one leaf attached to a plate as shown, a quicker and more regular action is obtained.

A "clock" in the possession of the author, which is made on the principle here shown, contains 400 mgs. of 0·1 per cent. radium-barium-bromide. The period is about 28 minutes.

be remarked that the period appears to be limited by the durability of the gold leaves rather than the diminution of the electrical charge derived from the radium.

The attraction which takes place between the leaves and the earth plates as the former gradually diverge, causes their final movement to be very rapid, but the rate at which the leaves acquire a charge varies, of course, with the quantity of radium within the tube, and also on the state of the vacuum within the bulb.

With very impure radium salts the cycle may occupy several hours, but a period of a minute or less can be obtained with a few milligrams of a nearly pure radium compound. The action of the β rays is only indirect, and, owing to their power of penetration, they pass through the tube and the glass bulb into the outer air.

37. Spectroscopic Observation of the Luminosity of Radium Salts.—It has already been stated that radium salts are self-luminous. The light is usually brighter with impure salts containing a large excess of barium, pure radium bromide exhibiting only a faint luminosity. The light emitted by a practically pure specimen of radium bromide was examined spectroscopically by Sir William and Lady Huggins. A preliminary observation indicated that the spectrum was not continuous, and a special quartz spectrograph was employed to obtain a photograph of the spectrum. After an exposure of three days, a time necessitated by the exceedingly faint character of the light, a negative was obtained which showed a spectrum of lines and bands. A careful examination of the relative positions and intensity of the lines proved that they were due to nitrogen, the spectrum exhibited being identical with that obtained from a vacuum tube containing this gas. Such a result must be regarded as very remarkable, and shows that part, at least, of the observed luminosity of very active radium compounds does not come from the fluorescence set up in the substance

itself by its own radiations, for such light appears to almost always show a continuous spectrum.

The explanation appears to be that the intense ionisation of the air in the immediate proximity of a very active radium salt is capable of rendering it luminous in a similar manner to the passage of an electric discharge in a vacuum tube. The action is naturally very feeble in comparison, but nevertheless strong enough to bring out the characteristic spectrum of nitrogen with sufficient intensity to admit of its identification with a long enough exposure. The ionisation is, of course, equally distributed all round the active surface, and the light appears to proceed from the air close to it like the glow around the electrode of a vacuum tube. In addition to the nitrogen spectrum there is probably also a faint continuous spectrum due to a true fluorescence set up in the salt itself, and a spectroscopic observation of the stronger luminosity of impure salts, where the ionisation is not great enough to cause a visible luminosity in the surrounding gas, would doubtless give evidence of this. In support of the idea that the spectrum is due to atmospheric nitrogen rendered luminous by the ionisation produced, it may be stated that no evidence of a similar spectrum was obtained when the radium was enclosed in a highly exhausted bulb. It is important to distinguish clearly between the spectrum of the faint luminous glow shown by many radium salts and the spectrum of the element itself. Although the production of a nitrogen spectrum is very wonderful, it might, perhaps, be expected if the ionisation is intense enough, and the fact that the radiation from radium is just sufficient to effect it is another proof of the astonishing activity of this element.

PART II

I

38. Radio-active Products.—The nature and properties of the radiation emitted by the radio-active elements have been briefly described, and this radiation has been shown to consist of the projection of particles of atomic dimensions which carry a positive charge, and also of electrons accompanied by rays which are probably irregular etheric pulsations as distinguished from the isochronous undulations of light. It is now necessary to describe certain other properties of the radio-active elements which, although seeming at first to add further complication to already complex phenomena, have, in reality, led to a full and consistent theoretical explanation of radio-activity. This explanation has evolved from the observations obtained throughout a long and detailed series of experiments, an account of which cannot with advantage be given here. All that is aimed at is a concise presentation of the facts which these experiments have brought to light, and their explanation according to the now established theory of atomic disintegration.

The wonders of the radio-active elements are not exhausted by the analysis and explanation of their rays, for a study of their properties has brought to the knowledge of science several new and hitherto unsuspected forms of matter of very great importance, and a series of connected

phenomena, the interpretation of which has led to a closer knowledge of that obscure mystery—the atom.

39. The Activity of Thorium.—In the investigation of the radio-activity of thorium, it was discovered that thorium oxide was a very inconstant source of radiation, considerable variation in the activity being produced by slight air currents passing over the surface of the active compound. This variation was not observed, however, when the thorium was placed in an enclosed vessel for, in this case, the radiation reached a steady value after a period of increase. Experiments conducted with a view to discovering the cause of the observed variation showed that a steady stream of air, drawn over the compound, carried with it some form of matter which was itself radio-active, and to the presence of which within the thorium compound part of the total observed activity was due. It was clearly proved that the activity was not caused by any form of dust carried away from the thorium, for the active constituent behaved in every respect like a radio-active gas, diffusing readily in air and passing through porous forms of matter like paper or the wool fitted into the tubes through which the air containing it was drawn.

To this supposed active gas the name "thorium emanation" was given, and its connection with the activity of thorium will be discussed later.

40. Thorium X.—It has been shown by Profs. Rutherford and Soddy that a highly active form of matter can be separated from thorium compounds by chemical treatment.

The addition of ammonia to a thorium solution will cause the precipitation of the thorium, but the greater part of the activity remains in the filtrate, and a small, but very radio-active, residue is obtained when this is

evaporated and freed from ammonium salts by ignition. This active residue is not thorium, but appears to contain some unsuspected form of matter which, weight for weight, is many hundred times as active as thorium, and which, distributed throughout the mass of any thorium salt, contributes to its apparent radio-active properties.

41. Decay of Activity.—The radio-activity of the residue obtained proved, on examination, to be only temporary, for after an interval of a month it had become inactive; the thorium from which it had been extracted, however, proved to have *completely recovered its activity in the same period.*

This recovery of the thorium activity made it possible to repeat the process indefinitely, for it seemed that thorium was constantly evolving the active matter to balance the decline of its activity. The total radio-activity of thorium is thus partly due to the products to which it gives rise existing at their equilibrium values within its mass. The active matter in the residue obtained after the precipitation of the thorium from solution was called "thorium X" on the analogy of a similar active constituent previously isolated from uranium by Sir W. Crookes, and called by him "uranium X."

The activity of uranium and thorium, however, has been stated to be a property of the elements themselves and quite independent of their states of chemical combination. The isolation of uranium X left the uranium photographically inactive; but after a time the activity of the uranium X vanished, while the uranium spontaneously regained its lost activity in the same time. The conclusion appeared inevitable that, although the property of radio-activity is a specific property of the elements themselves, it is at least partly so because they

are able to spontaneously evolve other active forms of matter which are occluded within their substance. A curve plotted to show the decline of the activity of uranium X is exactly symmetrical with the curve of recovery by uranium of its initial activity. A similar curve can also be drawn to represent the decay of thorium X, and the recovery of the activity of the thorium, but in this case there are small initial irregularities in the curves which need not be discussed now.

The statement that the radio-activity of thorium and uranium is a specific and unalterable property of these elements is quite true, for it is only possible to *remove* the active products, not to arrest their formation. Neither is it possible to modify to the slightest degree their periods of decay and recovery. The statement only needs qualification to the extent that some of their observed activity is a property of the products to which they give rise.

It now becomes a matter of importance to discover the periods of decay and recovery with more exactness, and also to discover the mutual relations of the products and the proportions of the total activity for which each is responsible.

42. Uranium X.—The activity of the uranium after the removal of the uranium X was first tested by the photographic method, and was found to have disappeared, while the whole of the activity was concentrated in the isolated uranium X. This was, however, somewhat misleading, as the photographic action was dependent on the β rays.

The uranium was still active, but emitted only α rays, which, under the conditions of experiment, did not give rise to photographic action. The radiation from the

isolated uranium X consists of β rays, which, although responsible for nearly the total photographic effect, would not, by their absence, considerably modify the observed activity of the uranium if tested by the ionisation method.

It is thus evident, that although uranium emits all three types of rays, the β rays (and hence the γ rays also) are due to the product which it evolves; the uranium *itself* being radio-active, but emitting only α rays.

43. Periods of Decay and Recovery.—The period of a radio-active product expresses the time necessary to allow its activity to fall to one-half its initial value. Accurate measurements of the decay of activity of uranium X show that the activity falls to half its initial intensity in a period of about twenty-two days.

In this same period the uranium from which the uranium X was removed recovered half of its lost activity. The period of decay of activity in the case of thorium X is much shorter, occupying about four days, and being balanced by a recovery of activity in the thorium from which it was removed in the same period.

The case of uranium may be thus represented—

Uranium emits α rays and evolves
Uranium X, which emits β and γ rays and declines to half its original activity in twenty-two days.

The questions now arise: What becomes of the uranium X? Does it, in its turn, give rise to another active product, or decay into some inactive form of matter? What position does thorium emanation occupy with respect to thorium and thorium X? Lastly, What can be the theoretical explanation of such astonishing and complex phenomena exhibited by forms of matter which

there is every reason to consider as elementary? These questions will be dealt with later, but before discussing the theoretical side of the subject it is necessary to mention the case of radium and some properties of the emanation it evolves.

II

44. Radium Emanation.—The production of a radio-active emanation by radium was recognised soon after the discovery of the element itself, and, owing to the high activity by which this emanation is characterised, it has been investigated in considerable detail by many physicists.

Inactive matter placed in close proximity to an uncovered radium compound soon acquires a very considerable activity by reason of the deposition of the emanation over its exposed surfaces, and this activity persists for a considerable period after the removal of the radium.

It was at first thought that the production of such activity was due to the mere presence of radium causing ordinary forms of matter to temporarily manifest radio-active properties, but it soon became evident that the nature of the matter exposed to radium had no apparent effect on the intensity of the excited activity. Experimental investigation soon showed the true nature of this excited activity, for all action is completely stopped by enclosing the radium in a sealed glass tube, or otherwise preventing the escape and diffusion of the emanation into the surrounding space. To this apparent activity, due to the deposition of the radio-active emanation on the surface of inactive matter, the expression "induced activity" has been applied. This is, perhaps, somewhat unfortunate, for

it conveys the idea of an action similar to that exhibited in electrical and magnetic phenomena; so long as the true nature of this activity is remembered, however, this expression need not cause confusion.

45. Properties of Radium Emanation.—The emanation is not liberated very freely from dry radium salts at ordinary temperatures, being occluded within the compound itself, but it is given off much more copiously if the radium is heated or, better still, dissolved in water or other solvent, as it can then be removed from the radium and its properties observed.

In all respects the emanation behaves like a very radio-active gas, and it becomes important to inquire into the nature of this activity. The gaseous character of the emanation is indicated by the following experiment. A small glass vessel, closed with a stop-cock, contains a quantity of a radium salt in solution. This is connected by a tube with a similar vessel in which is placed some fluorescent zinc sulphide or willemite. On viewing the second bulb in a darkened room, no fluorescence will be observed while the stop-cock remains closed, but on opening it the emanation will diffuse along the tube connecting the two vessels, its presence in the second bulb being indicated by a brilliant fluorescence set up in the compound contained in it. This result cannot be attributed to any direct action of the rays emitted by the radium itself, as such an action would be independent of the turning of the stop-cock. It is very clearly the result of the activity of the supposed gaseous emanation which diffuses through the air and distributes itself equally between the two vessels; this diffusion of the emanation takes place freely through porous substances, but is completely stopped by a thin piece of mica.

46. Condensation.—A very beautiful variation of the above experiment, and one which gives additional evidence in favour of the idea of the gaseous nature of the emanation, is performed by passing a slow stream of air carrying with it the emanation through a glass tube shaped in the form of the letter **U**, and which contains fragments of willemite. The presence of the emanation in the tube is marked by the glowing of the willemite, which becomes much more marked after the immersion of the **U**-tube in liquid air. In this case the emanation is condensed in the tube by the extremely low temperature, and its action is more localised. A steady stream of air may now be passed through the tube without removing the emanation until the temperature has again risen considerably.

Profs. Rutherford and Soddy have made an extensive experimental inquiry into the temperature of condensation of radium emanation, their results showing that condensation is complete at a temperature of $-150°$ C.

47. Decay of Activity.—The activity of radium emanation shows a very marked decrease after the lapse of a few days. Measurements of the rate of decline give a period of 3·7 days as the time in which the activity falls to one-half its initial value.

The radium from which the emanation has been removed spontaneously regains activity at the same rate as the isolated emanation loses it, and ultimately recovers its original intensity of radiation owing to the accumulation of the emanation again in its equilibrium amount. The activity at any moment is then represented by the balance of these two opposing processes; the loss of activity by the emanation and the simultaneous evolution of fresh emanation by the radium. The curves showing the decay

of the activity of the emanation and the recovery of the activity of the radium are thus symmetrical.

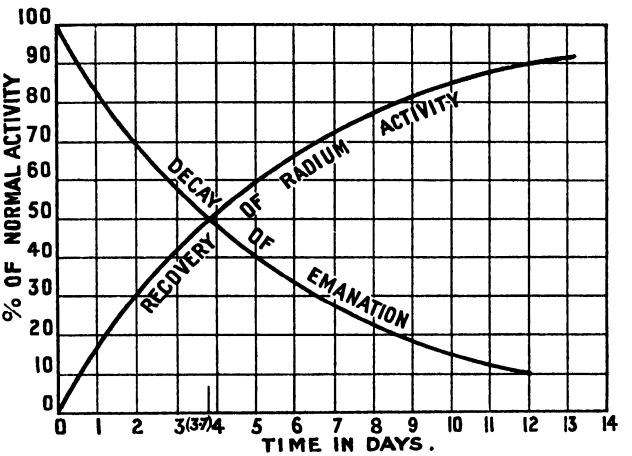

FIG. 10.—Curves showing rate of decay of the activity of radium emanation and the simultaneous recovery of activity by the radium from which it was separated.

48. Excited Activity.—The property possessed by radium of apparently causing objects in its neighbourhood to become radio-active has already been stated to be due to its emanation deposited over their surfaces. It was soon discovered, however, that this excited activity exhibited properties which were only explicable on the assumption that the emanation, in its turn, evolved another form of radio-active matter which took the form of an invisible solid deposit distributed on the surfaces with which the gaseous emanation had been in contact.

Such a deposition of an invisible film of solid active matter was first observed in the case of thorium emanation,

and radium emanation was shortly afterwards discovered to possess a similar property. Early experiments proved that this activity was directly due to contact with the emanations of thorium and radium respectively, and was not due in any way to the rays. It is thus very important that there should be no confusion between this deposited activity and the secondary radiation mentioned in Part I. Secondary radiation persists only as long as the primary rays fall on matter and is directly due to their action; also the intensity of the secondary rays varies with the nature of the matter acting as radiator. Excited activity, on the other hand, has no connection with the incidence of radiation from a radio-active substance, but is a direct product of contact with a radio-active emanation and persists for a considerable period; moreover, the nature of the matter on which the activity is deposited is of no consequence in the determination of its intensity or the nature of the radiation which is emitted.

This excited activity has been very closely investigated, and has been shown to possess a complex nature consisting of successive active products with various periods of decay.

49. Distribution of the Rays.—The question of the distribution of the total activity of radium between the element itself and its several active products is one of great interest.

Does the radium, from which the emanation and active products have been entirely removed, show activity, and if so, what type of radiation is emitted? The answer is that radium, immediately after the removal of the emanation which is normally occluded within its mass and the products to which the emanation gives rise, emits only α

rays and retains about 25 per cent. of its original activity. This α-ray activity is an unalterable property of radium itself without regard to any active products which the radium may also evolve. The remaining 75 per cent. of the activity normally exhibited by radium is due to its emanation and the products arising from it.

The gaseous emanation itself emits also only α rays, but the active deposit emits all three types—α, β, and γ rays. It is thus evident that the radiation from radium, complex in itself, arises from a complex source, and a further analysis of the question becomes a matter of importance.

III

50. Theoretical Considerations.—The phenomena of radio-activity and the properties exhibited by the radio-active elements appeared so wonderful and complex that any attempt at a clear and connected theory which would explain the facts in a scientific manner and in accordance with the accepted principles of physics seemed, at first, almost impossible. In the radio-active elements we have forms of matter which incessantly and spontaneously emit radiation without any discoverable source from which they can acquire energy, and without any perceptible loss of mass or change of properties. In the case of the highly active element radium, the radiation is of sufficient intensity to produce startling and almost incredible effects, which seem out of all proportion to the minute quantity of matter responsible for their manifestation. In addition to all this, these supposed elementary forms of matter are constantly evolving from their own mass other forms of active matter which, although existing in quantities far too minute to be visible, nevertheless give unmistakable evidence of their distinct nature and exhibit a relatively enormous activity.

The radiation which is emitted is also in itself a great enough marvel, for it will be remembered that, in addition to the projection of the atomic α particles, it consists also of electrons travelling with velocities which approach the

velocity of light itself, and which give rise to the propagation of an etheric disturbance of extraordinary penetrative power as exemplified in the γ rays.

The manifestation of energy is relatively very great, yet there is no sign of exhaustion, the property appears constant and immutable. What of the conservation of energy? The energy liberated by the radio-active elements must be derived from some source.

One of the earliest suggestions was that radium and the elements like it were merely instrumental in rendering perceptible some hitherto unsuspected form of external energy. An illustration of the nature of the supposed action is afforded by the fluorescence of certain substances when placed in a beam of invisible ultra-violet light. Such substances render evident by their luminosity a form of radiant energy of which we cannot be directly conscious.

It will not be necessary to elaborate a discussion dealing with this and similar suggestions, or to point out by many different analogies the wonder of a constant manifestation of energy without any evident source from which that energy is derived and maintained. The distinctive character of the phenomena is sufficiently marked, and this has been repeatedly emphasised in treatises on the subject.

The properties of the radio-active elements remain unaffected when they are screened by metallic lead from any hypothetical source of energy derived from without, and are constant over a wide range of temperature; indeed, human agency appears powerless to check the emission of energy.

The distinctive nature of the active products is shown by their behaviour in various chemical processes and by

their periods of decay, but their evolution from the element which gives rise to them is continuous and invariable.

Any theory based on the assumption of the transformation of external energy by the radio-elements is incompetent to explain their properties in a satisfactory way, and the more progressive and less conservative physicists were quick to realise this, favouring the idea that the solution to the mystery was to be sought within the elements themselves. The great advance which had been made in physical science, especially in connection with electricity, had prepared the way for the recognition of forces undreamed of previously, for it had given scientists an insight into the nature of, and forces within, the atom. The two branches of physics which have contributed the most conclusive evidence in favour of the theory that an atom is a highly complicated system, are optics and electricity.

51. Atomic Disintegration.—Apart from their radio-activity, radium, uranium, and thorium are in no way different from the inactive chemical elements. According to all chemical tests they *are* elements, exhibiting definite properties which determine their place in the periodic law, and giving, under the necessary conditions, characteristic spectra.

To Profs. Rutherford and Soddy is due the credit of formulating the now established theory of atomic disintegration. *According to this theory, radio-activity is an atomic property and due to the instability of certain atomic systems.*

How, then, are we to regard such an element as radium? The "disintegration theory" states that the radium atom is an unstable system, and that the radio-activity of radium is due to a certain definite proportion of the total number

of atoms forming any given mass of the element undergoing disintegration in a unit time. The energy manifested in radio-active phenomena is thus derived from within the atom itself.

As a clear comprehension of the theory of atomic disintegration is very important, it will be better to consider with more detail the above statements.

Even the most minute mass of matter contains an enormous number of atoms, and, in the case of a radio-active element, a certain definite proportion of the total number of atoms forming any given mass of such an element, become unstable and disintegrate in a given unit of time. This proportion is, in the majority of cases, exceedingly small, but its amount determines the intensity of activity by which the element in question is characterised. To consider the case of radium: an almost inconceivably small fraction of the total number of atoms in any given mass of the element disintegrate in a second, yet this insignificant fraction is sufficient to account for the observed manifestation of radiation for that period. In the case of uranium, the activity of which is so much less energetic, the proportion of atoms disintegrating per second is very much smaller still. The mere statement conveys no idea of either the stupendous number of atoms contained in, say, a milligram of radium, or of the incredibly small fraction of this number which pass through the condition of instability in one second. It has been found possible to arrive at a numerical estimate, however, which will express approximately the "period" of radium.

52. Radio-active Periods.—By the "period" of a radio-active element is meant the time which must elapse before its activity has declined to one-half of its initial intensity. In the case of the active products of uranium

and radium which have been already mentioned, the periods can be directly observed by testing the intensity of the activity after an interval of a few days or weeks. Thus in the case of radium emanation, the period is 3·7 days, and with uranium X, 22 days.

During the time in which radium has been under investigation, not the slightest appreciable decline in its activity has been observed, and, although the observations only extend over a few years, it is certain that the period of radium must be exceedingly long.

53. Explanation of Rays on the Disintegration Theory.—The questions now arise as to how the rays emitted by the radio-elements are explicable on the theory of the disintegration of their atoms. The processes will be much clearer on discussion of the probable structure of an atom, but a preliminary explanation may now be given. To consider first the case of radium itself without regard to its emanation or the succeeding products. It has been stated that the element itself emits only α rays. This emission, according to the disintegration theory, is due to the instability of certain atomic systems, and it will be clearer to speak of one particular atom and consider it as typical of many, the process being in all cases the same. With the occurrence of the condition of instability, a complete disruption of the atomic system takes place, and, in the process, part of the system, or, to put it more concretely, a part of the atom, is projected into space with great velocity. *This fraction of the original atom is the α particle*, and its velocity of projection, as stated in Part I., is about $2{\cdot}5 \times 10^9$ cms., or roughly, some 15,000 miles per second. The α particle is thus a component part of the radium atom *before* disintegration, and a distinct and separate atom of small atomic weight *after* its escape.

54. The Disintegration Theory in Relation to Active Products.—It will now be natural to inquire about the production of radium emanation. The oncoming of instability in the radium atom was marked by the expulsion of an α particle, an atom of small atomic weight the value of which, although not definitely determined, appears intermediate between hydrogen and helium. What of the large portion of the original radium atom from which the α particle is projected? Does it attain to a condition of stability and form a new permanent atom, or does it again undergo disintegration? The facts of radio-activity render it evident that an atom of radium emanation is nothing but the new atom resulting from the disintegration of the radium atom itself; indeed, it is the large fraction of the original atom which remains after the emission of the α particle.

The intense activity of radium emanation is ample proof that the new atom is a very unstable system and again quickly undergoes disintegration. As in the case of radium itself, the instability of the atom of the emanation is marked by the expulsion of a second α particle, and the resultant atom is the atom of the first active deposit. It has already been mentioned that the invisible solid deposit left by the emanation is the active product responsible for the β and γ radiation from radium. The case is, however, much more complicated than this direct statement would imply, as the first active product again emits only α rays.

The investigation of the radium products has been a difficult matter, demanding much delicate quantitative work. Many experimentalists, however, have contributed to elucidate the complex problem presented, and the result has been to demonstrate the existence of a wonderful series

of active deposits resulting from the disintegration of the emanation.

55. Period of Radium.—The possible cause of disintegration of an atom is considered in connection with its probable structure, but it seems certain that it cannot strictly be regarded as chance. Each individual atom must have its moment of disintegration determined by physical causes, either internal or external, but when the number of atoms is so vast it becomes quite permissible, for purposes of calculation, to treat the condition of instability as a chance occurrence for any particular atom. It then becomes possible to deduce the period of the radio-active element in question, and also to estimate the average life of its atoms.

Owing to the fact that no appreciable variation in the activity of radium has been observed during the time it has been under investigation, its period cannot be directly determined, but an estimate is possible from a consideration of the number of α particles which are emitted from a known mass of radium at its minimum intensity of radiating power, that is to say, when deprived of its emanation and the derived active products. In order to estimate the number of α particles expelled from a given amount of radium, it is necessary to measure the total electric charge derived from the absorption of the α rays by metal, and divide the result by the charge carried by one α particle. The experimental determination of such a charge is a matter of extreme difficulty, and many complicating factors are involved, which render an account of the method employed too technical and intricate to be given here. The number of α particles emitted by one gram of radium at its minimum activity (*i.e.* after the removal of the emanation and succeeding products)

in one second has, however, been estimated, and so also has the total number of atoms forming the mass of the gram. As the number of α particles emitted per second represents the number of atoms which undergo disintegration in the same time, on the assumption that the disruption of the atom is accompanied by the expulsion of one α particle, the proportions of the two quantities obtained indicate the period of radium. Prof. Rutherford gives the number of atoms which undergo disintegration per second per gram of radium at minimum activity as

$$6{\cdot}2 \times 10^{10}$$

The number of atoms of radium contained in a gram is estimated at

$$3{\cdot}6 \times 10^{21}$$

So that the fraction disintegrating per second is represented by

$$1{\cdot}95 \times 10^{-11} \text{ or } 5{\cdot}4 \times 10^{-4} \text{ per year}$$

This would correspond to the transformation of about 0·5 mg. per gram per year, and would indicate that the period of radium is about 1300 years.[1] This is a marvellous result, for it means that for centuries the activity of any given quantity of radium will continue practically uniform, and when the intensity of the radiation is remembered, some faint idea can be formed of the enormous forces latent in an atom. From what has been stated, it will be clear that the duration of the activity of any radio-active element is a constant for

[1] A distinction is to be made between the period of a radio-active element and the average life of its atoms. This latter value in the case of radium is given by Prof. Rutherford as 1800 years.

that element, and quite independent of the quantity under consideration.

56. Disintegration Products of Radium.—The active products of radium have been very closely studied by several physicists, especially Prof. Rutherford, and eight distinct forms of active matter are now known. Much experimental work has been involved in the investigation, and the problem has been one of no small difficulty, owing to the exceedingly small quantities of matter under observation; indeed, quantities so small that the only indication of their existence is afforded by their activity.

Although all ordinary methods of investigation are therefore impossible, the properties of the various products can, to a certain extent, be studied by following up, through different chemical processes, the radio-activity which betrays their existence. By such means it is possible to analyse the activity deposited by the emanation, and to prove that it consists of the radiation from several successive products, certain of which possess, in addition to distinctive chemical properties, some physical characteristics, such as a definite temperature of volatilisation.

Owing to the fact that the various products were not discovered in the order of their natural sequence it was, in the earlier stages of the work, a somewhat difficult matter to decide on a satisfactory method of naming them. The nomenclature now adopted is to distinguish the products succeeding the emanation by the capital letters of the alphabet preceded by the symbol of the element from which they originate, *i.e.* radium.

In every case after the emanation the products take the form of solid deposits, and each has its own characteristic period of decay.

Five of the products emit α particles, but with varying

velocities, and hence the radiation in each case has a different ionisation range.

The successive disintegration of the radium atom as exemplified by the disintegration products is shown in the following table, which represents, according to Prof. Rutherford, the complete radium series as at present known.

	Element.	Radiation emitted.	Period.	Range of α particles in air at normal pressure.
	Radium . .	α particles	2000 years [1]	3·5 cms.
	↓ Emanation .	α particles	3·7 days	4·3 cms.
Rapid change	↓ Ra. A . . .	α particles	3 minutes	4·8 cms.
Rapid change	↓ Ra. B . . .	β particles	26 minutes	—
Rapid change	↓ Ra. C . .	α and β particles; γ rays	19 minutes	7·06 cms.
Slow change	↓ Ra. D . . .	?	40 years	—
Slow change	↓ Ra. E . . .	?	6 days	—
Slow change	↓ Ra. F . .	β particles	4·5 days	—
Slow change	↓ Ra. G . . .	α particles	140 days	3·86 cms.
	↓ ?			

[1] The values 1800 years for the period, and 1800 years for the average life of the radium atom, are given by Prof. Rutherford in his work, "Radio-activity." The above value of 2000 years is given by him as a later determination.

Each of the above products represents an unstable atomic system, and in each case, with the exception of the products Ra. D and Ra. E, some form of particulate radiation is emitted. It is quite possible that such radiation also accompanies the disintegration of the atom of the products D and E, but if the velocities of the emitted particles are below the critical velocity of ionisation, it would probably escape detection by the methods of investigation at present available.

The atom formed after the disintegration of Ra. G is apparently a stable system, for the final product is not distinguished by any discoverable radio-activity. There is, however, some indirect evidence as to what this final product may be, and further mention will be made of it.

57. Polonium and Ra. G.—It will be seen that Ra. G emits only α rays. There is strong evidence from its properties and period of decay that Ra. G is identical with polonium, the first active-substance isolated from pitchblende by Mme. Curie. Ra. G thus appears to be chemically allied to bismuth, for the polonium of Mme. Curie seems never to have been completely separated from this element.

58. Radio-active Equilibrium.—If a radio-active element be left for a considerable period so that its disintegration products can accumulate, it reaches a condition known as radio-active equilibrium. In this condition the products exist in constant amounts, the decay of each being balanced by its simultaneous evolution from the product preceding it.

IV

59. Atomic Structure.—The problem of the atom is one of the most fascinating as well as one of the most difficult with which physical science has to deal. The idea of the atom being a strictly indivisible unit has long been untenable, and recent discoveries have not only confirmed the theory of its divisibility but have proved that, whatever the exact nature of the atomic system may be, it is, at least, a system of considerable complexity.

The theory that the atoms of the chemical elements are built up of simpler units is suggested by the observation that certain physical and chemical properties periodically recur in groups of the elements considered in order of their atomic weights. The elements of group II. of the periodic law may be taken in illustration of the periodicity referred to. These elements fall into two subgroups in which the similarity of properties is most strongly displayed; they are here given with their atomic weights.

Calcium (40·1).	Beryllium (9·1).
Strontium (87·6).	Magnesium (24·1).
Barium (137·4).	Zinc (65·4).
Radium (226·0).	Cadmium (112·4).
	Mercury (200·0).

Elements with atomic weights intermediate between these values are absolutely different in their properties, fourteen being known with atomic weights falling between those of calcium and strontium, yet the distinguishing

characteristics of calcium find no parallel until a certain increase in atomic weight has been attained, when similar but slightly modified properties of the atom recur and are exemplified in strontium.

These relations, which are very closely manifested throughout the list of known elements, are a strong indication that their atoms are formed of some fundamental unit, and that the properties of an element are determined by the arrangement as well as the number of the unit particles which constitute its atoms. It is not, perhaps, strictly accurate to say that the properties of an element are determined completely by its atomic weight, but the two are so related that, when the atomic weight is known, the properties of the element can be indicated with considerable certainty.

One of the first suggestions in explanation of atomic structure was that the atoms of the various elements were aggregations of the hydrogen atom which, being the lightest atom known, was taken as unity. The decimals which occurred in the determinations of the atomic weights of several elements were regarded as probably due to experimental error. It soon became clear, however, that the values obtained which involved decimals were too persistent to be explained in this way, and that the atomic weights were, in many cases, certainly not whole numbers, as would necessarily be the case if all atoms resulted from aggregations of the hydrogen atom. Yet the relations of the elements, as indicated by the periodic law, are so striking that it is impossible to resist the conclusion that they are the result of a real similarity of atomic structure determined by a similarity of configuration of some unit particles from which their atoms are built up. Science owes the full enunciation of the

periodic law to the distinguished chemist Mendeléeff, and it is unthinkable that the relations so clearly exhibited by the elements are the result of pure chance, for the validity of the periodic law has been demonstrated repeatedly by the manner in which every newly discovered element fits into some vacant space in the list of elements which had previously indicated its probable existence.

Even if the hypothesis that the atoms of the elements were systems built up of the hydrogen atom had been found consistent with determinations of atomic weights, it would nevertheless have left the problem of the hydrogen atom itself as obscure as ever. The rapid progress of physical science and the recognition of the particulate nature of negative electricity, have led to the formation of a theory of atomic structure which, if not yet complete, is nevertheless able to offer a consistent explanation of many complicated phenomena met with in the various branches of physics, including the facts of radio-activity.

60. The Electron Theory of the Atom. — The electron theory presents the most comprehensive and consistent explanation of physical phenomena that science has yet been able to offer. Its application is very wide, but it need only be briefly considered here in its relation to radio-activity.

A study of the ionisation of gases proves that the negative ion (*i.e.* the electron) is always invariable in character, while the positive ion varies with the nature of the gas in question. This is in accordance with the view that the process of ionisation consists of the removal of an electron from the neutral gas atom. The positive ion is therefore the original atom deprived of an electron, and its mass and nature must necessarily be determined by

the particular gas ionised. Whatever the nature of the atom may be, considered as a whole, at least one electron forms an essential part of it.

It appears certain that all the observed properties of an atom are functions of the electric charge or charges associated with it, and there is every reason to believe that chemical affinity is electrical affinity, explicable by the properties of the electrons associated with atoms.

This is a broad generalisation, but although the laws which govern the manifestation of such affinity in any special case may not be accurately known, it seems impossible to doubt that its nature is electrical.

A consideration of the subject of radiation and many of the phenomena met with in optical research, shows the necessity of the existence of electric charges within, or in close association with, the atom. Light consists of the propagation of electro-magnetic waves in the ether, and a study of the nature of the radiation yields valuable information as to the processes occurring within the radiating source.

Spectroscopic analysis not only proves the existence of oscillating charges in close connection with the atoms of the radiating element, but also that the frequency of the oscillations, which determines the colour of the emitted light, is a characteristic of the element in question, and implies that a certain electron system is a distinguishing feature of its atom.

Consideration will show that a theory which assumes the particulate and discontinuous structure of matter involves the necessity for the existence of a medium by means of which the interactions of the particles can take place and their properties be manifested. The only medium known to science which can supply the necessary

connecting link is the ether, and one of the facts which physical research has served to establish is that connection between matter and the ether can only be brought about by means of an electric charge. This is very important, for it is the expression of one of the widest possible generalisations.

The association of electrons with atoms in all forms of matter is amply demonstrated, but without reference to any electrons which may be in connection with the atom, and by means of which certain of its properties are manifested, the electron theory also accounts for the atomic system itself and explains, not only the relations exhibited in the periodic law of the elements, but also the phenomena of radio-activity. The development of the electron theory as applied to the atom, is largely due to the work, both theoretical and practical, of Prof. J. J. Thomson.[1]

✓ According to recent views, resulting from much experimental work on the subject, the atom consists of a system of electrons in rapid orbital revolution within a sphere of uniform positive electrification. The number of electrons in the system determines the weight of the atom, and their configuration and arrangement, its physical properties.

The theory postulates a uniform sphere of positive electrification as a necessary condition for the stability of a system of negative electrons.

In all electrical phenomena the electron plays the active part; its existence proves the particulate nature of negative electricity. Positive electricity, however, never appears apart from matter; that is to say, it is always encountered in inseparable association with the atom, and all attempts to find a positive unit, equal and complementary to the electron, have completely failed.

[1] Now Sir J. J. Thomson.

This has given rise to the statement that electricity is particulate, although, of course, the assertion really refers to negative electricity, which, being free from any necessary material connection, forms the active agent in contrast to the part played by positive electricity, which is passive and apparently incapable of existence or movement apart from the atom. Positive electrification, therefore, under whatever circumstances it may be found, always indicates a deficiency of the electrons necessary for a state of electrical neutrality.

61. Number of Electrons in the System.—From the knowledge gained from the investigation of the kathode rays, it will be clear that a hydrogen atom must be a system of some eight hundred or a thousand electrons on the assumption that its mass is entirely due to them, and that other atoms represent systems of a complexity indicated by their various atomic weights, an atom of mercury consisting of some 200,000 electrons. At first sight it may appear almost incredible that this vast system can exist within the volume of an atom, but an investigation of the question will show that, not only are the electrons not crowded, but that, on the contrary, they are separated by intervals which are relatively enormous in comparison with the space they actually occupy. Although the matter can be subjected to calculation, an approximate idea will serve, and may be gathered from the statement that if a fairly large lecture hall be taken as representing the volume of the atom, the electrons on the same scale would be represented by bodies about the size of a pea.

The period of revolution of the electrons within the atom is not known with any certainty, and no doubt varies with different atoms, but it is most probable that several billion revolutions are performed in one second.

In connection with this supposed revolution occurs the very important question as to how it is possible for the atoms to exist for age after age, without the energy of the electrons being exhausted in setting up radiation in the surrounding ether. Calculation shows that a single electron would very quickly lose its energy by radiation, even if it were initially revolving with the enormous speed indicated. It has been shown, however, that the argument which applies to an electron considered singly must be much modified when the case is that of a large number distributed round the circumference of a circle; and in addition to this, there are the unknown factors introduced by the circumstance that the revolution is, hypothetically, performed within a sphere of positive electrification.

In support of the idea that the electrons are thus revolving, and do not merely constitute some electrostatic formation, the velocities of the electrons forming the β rays may be mentioned.

To suddenly endow an electron with such a velocity would need an incredible concentration of force upon it, for the time in which the velocity would have to be imparted would be only that inconceivably minute fraction of a second during which the electron was flying free of the atomic system. The observed facts seem to point strongly to the conclusion that the velocity of the electron is not due to any such violent acceleration, but to the orbital velocity it already possessed when constituting a part of the atom.

62. The Electron Theory and the Periodic Law.— In the electron theory of the atom can also be found an explanation of the relations shown in the periodic law, for it seems certain that definite physical and chemical

properties are associated with definite arrangements of the electron system, and that the similarity of atomic structure exemplified in the elements of a sub-group is only possible at definite atomic weights. This is well illustrated by an experiment performed with floating magnetic needles in a uniform magnetic field. A number of short magnetic needles are floated on the surface of water by being inserted through small pieces of cork, and are so arranged that like poles are all pointing upwards. They will, of course, repel one another outwards, and distribute themselves round the edge of the containing vessel. The approach of the pole of opposite sign of a more powerful bar-magnet from above, will attract all the smaller magnets, and cause them to draw together against their own repulsions, forming a geometrical figure, the shape of which will depend, of course, on their number.

In the performance of this experiment the small magnets are to be considered as representing the electrons, and the field of the large magnet as the sphere of uniform positive electrification.

Observations of the configurations assumed by the small magnetic needles as they are introduced one by one on the surface of the water, will show a series of relations closely analogous to the relations set forth in the periodic law of the elements.

As an example of this periodicity the cases of four and twelve needles may be taken. Four set themselves in a square, and this figure is not again observed until eight more have been introduced, when it occurs as a central figure with eight forming an octagon round it. Similar relations are noticed with other figures, as in the cases of seven and sixteen. Seven take the form of a hexagon with one occupying the centre, and this formation

does not occur again until the needles number sixteen, when it is seen as a central figure surrounded by a ring of nine.

If four needles arranged in a square be considered as representing, say, an atom of beryllium (9·1), the formation assumed by twelve would represent an atom of magnesium (24·1), the next element in the same subgroup, while the different intermediate formations would correspond to elements of intermediate atomic weights which show no great similarity in their properties.

Owing to the difficulty of obtaining a large number of needles with a practically uniform intensity of magnetisation, the larger figures are not always easy to form, but when accurate, the continuation of the periodicity is clearly evident and is very suggestive of a probably analogous scheme of arrangement in the complex systems of electrons which are supposed to constitute the atoms of the elements.

63. Stability of the Atom.—The fact that the electrons forming the atomic system are in motion, does not destroy the value of the considerations suggested by the experiment with the magnetic needles, although it introduces a modifying condition.

The stability of a system of eighteen needles can be totally destroyed by the removal of only one of them, necessitating the complete rearrangement of the entire figure. The question of the cause of instability in an atom is very important. An unstable condition would doubtless result from the withdrawal of a sufficient number of electrons from the system, but it is difficult to see how this could occur except by means of some external agency. If such removal resulted from forces within the atom, it would itself constitute, not cause, a condition of instability.

The theory which seems most probable, and which has received the greatest support, is that stability is possible in a given atomic system only while the orbital velocities of the electrons are above a certain critical value. A rough analogy is found in a top, which will maintain an upright position only while it is spinning above a certain critical velocity of rotation.

If, by any means, the orbital velocities of the electrons should be reduced, the atom would remain stable until the critical value was reached, when there would be a sudden rearrangement of the system, and in the process, certain electrons or groups of electrons would probably make their escape, flying free from the atom with velocities which would be determined by the conditions of the case.

64. Possible Cause of Instability.—It is clear that if an electron is performing a periodic movement which will result in the emission of electro-magnetic radiation into the surrounding space, part of its energy must be expended in the process, and it seems quite possible that the atoms of the various elements may be continuously emitting an exceedingly feeble and undiscoverable form of radiation which serves to gradually reduce the velocities of the electrons below the critical value necessary for stability.

In some atoms the necessary reduction will be very much greater than in others, and these will constitute the atoms of the more stable elements, but, on this view, no atom is eternally stable. According to Prof. Thomson, the condition of instability is marked by the total internal rearrangement of the system, and hence the formation of a new atom with distinct chemical and physical properties, the potential energy of the system being decreased and the kinetic energy increased.

65. Theories of the Atom.—There is no theory of

atomic structure at the present time which is entirely satisfactory from all points of view. The one given above, although open to certain objections, offers a scientific and connected explanation of a wonderful range of facts, and, as the value of a theory is directly proportional to its power of explanation, it is the best one to provisionally accept in the theoretical conception and interpretation of radio-activity. It should, however, be remarked that it cannot be considered as proved, and that the disintegration theory of radio-active phenomena is not necessarily dependent on its validity.

Various other hypothetical conceptions as to the nature of the atom are mentioned in Sir Oliver Lodge's work, "Electrons or the Nature and Properties of Negative Electricity" (pp. 148 *et seq.*, and pp. 160 *et seq.*). The only other of these which need be mentioned here is the one which assumes the atom to consist of a system of electrons revolving round a positive unit of extreme concentration, like the planets round the sun. There are difficulties connected with this conception as with the others. The facts of radio-activity seem practically inexplicable on this theory, especially with reference to the formation of the various disintegration products, unless it be assumed that the atom consists, not only of one positive unit, but of several positive units, each with its own system of electrons, on the analogy of a multiple star system. It would then be possible to account for the emission of an α particle, which is an atom of small atomic weight with a positive charge, and the simultaneous formation of the atom of radium emanation. On this assumption the indivisibility of the positive unit would occasion no difficulty, as the α particle would be considered as one of the hypohetical sub-systems in the multiple system of

the atom which had escaped with its own attached electrons. The theory of the possible structure of an atom of matter on the plan of the solar system is dealt with in a most interesting manner by Mr. E. Fournier d'Albe in his work, "Two New Worlds." In this work the author endeavours to show the possibility of an atom not only resembling a solar system, but actually *being* a solar system in an infra-universe which man is able to recognise only as "matter," and although the work is mainly philosophical in its conception, the subject is also treated from the standpoint of physical science.

In connection with the science of radio-activity, however, the electron theory as developed by the work of Prof. J. J. Thomson is assumed as offering the best basis for interpretation.

The ultimate nature of the electron is unknown, and its discussion belongs, for the present at least, more to the realm of metaphysics. It is possible to conceive it as some modified and individualised form of the universal ether of space, but a more intimate knowledge of the positive electricity, which is always encountered in connection with the atom, is one of the most pressing needs of physical science. It is known that both the electron and the positive electrification associated with the atom are centres of a region of etheric strain, known as an electrostatic field, and in which the imagined lines of force are conceived to exist, but of the *internal* structure of either there is no definite knowledge, and it seems doubtful if the properties which are outwardly manifested, can be considered to exist within the space which, small as it is, they must individually occupy.

V

66. The Electron Theory and the Rays of the Radio-active Elements.—From what has already been stated, it will be clear that the most distinguishing feature of radio-activity is the emission from the active element of atoms with a mass which is apparently intermediate between that of the atoms of hydrogen and helium, and it is a matter of considerable interest to consider the phenomena presented in the light of the electron theory.

The occurrence of instability in the atom and the consequent rearrangement of the system, is marked, in nearly every case, by the emission of an α particle. In addition to any direct evidence that the α particle has a positive charge, it is certain that if many electrons escape in a group, they must necessarily carry with them a positive charge derived from the atom, for if such were not the case, the stability of the group would be obviously impossible, and the radiation would consist of scattered electrons and not α particles. The apparent uniformity of the α rays suggests the idea that an α particle may exist in an already formed state as a sub-atom within the atom from which it is ultimately emitted at the moment of disintegration.

As the α particle, in the case of radium at least, is not electrically neutral, it is clear that it carries with it rather more positive electrification than is necessary to balance the total negative charge due to the electrons, and it

might be expected from this that an atom of radium emanation would exhibit a negative charge, behaving, in fact, like a negative ion. Experiment shows, however, that the atoms of radium emanation are also positively charged, for the emanation is deposited much more readily on a plate or wire maintained at a negative potential than on neutral matter.

It thus seems necessary to assume that there is a simultaneous emission of free electrons from the atom with velocities below the critical velocity of ionisation. This would account for the positive charge exhibited by both the α particle and the emanation atom, while the comparatively low velocities of the electrons would render the radiation undiscoverable by any direct means.

Another suggestion about the α particle is that it is really neutral at the moment of emission from the atom, and that the positive charge is due to the fact that it becomes itself ionised by collision with the gas atoms in its path. This could be investigated if it were possible to observe the behaviour of the α rays in a powerful magnetic field while they were traversing a perfect vacuum, but the experimental difficulties are so formidable that it is almost impossible to obtain the necessary conditions. In the first place, it is essential that the α particles should escape collision with all matter from the moment of emission. This is an exceedingly difficult condition to fulfil, as not only would the vacuum have to be practically perfect, but the α radiation would have to proceed from a layer of active matter scarcely more than the diameter of a molecule in thickness in order to ensure that the α particles should escape collision with the active matter itself. As the α radiation from radium in radio-active equilibrium is deviable as a whole, a positive charge appears to be a

property of the α particles emitted from the disintegration products as well as from the radium itself.

Prof. Soddy has made some exceedingly delicate experiments with the object of observing the behaviour of the α particles under the above conditions, using the α radiation from an active deposit. The difficulty of obtaining a vacuum approaching the necessary degree of perfection, however, is so great that the experiments have not succeeded in conclusively proving that the charge of the α particle is due to ionisation by impact with matter.

67. Penetration of Matter by the α rays.—Although the power of penetration possessed by the α rays is only slight, it is nevertheless very remarkable when the facts are considered. The α particles can pass through a very thin piece of mica and still retain sufficient energy to cause ionisation of a gas. This means that an α particle must pass through an enormous number of molecules lying in its path, and it is scarcely possible to imagine, either that the molecules of the matter traversed are disturbed from their normal positions, or that the direction of motion of the α particle is subject to constant variation, so that it, so to speak, finds its way between them. Neither supposition seems in accord with the facts and probabilities of the case. Even the hardest and densest solids are penetrated to some extent and, when the atomic nature of the α particle is remembered, it will be evident that it is only its relatively enormous kinetic energy which renders this penetration possible.

In order to gain a mental picture of the probable occurrences when an α particle is stopped by impact with matter, it is necessary to consider the fact that, according to the electron theory, the spaces between the electrons in an atom are enormous in comparison with the space

occupied by the electrons themselves, so that it is quite possible for a small atom travelling with great velocity to pass straight through the system of another. The system of the α particle may be conceived as passing through the atoms of the solid into which it is flying, or through the gas atoms which lie in its path, as the case may be. It seems highly probable that the atoms of a solid are also ionised in the process, but in such a case there is no means by which the ionisation is directly evident, as the ions are rigidly locked in the mass of the solid. An approximate analogy may be suggested by the supposed passage of one solar system through another. It is possible to conceive that this might result in the loss of a planet which would roughly correspond to the process of ionisation.

Whether the α particle is initially charged or only acquires a charge by its first impact with matter, it cannot continue to lose electrons by ionisation on account of the fact that, when once positively charged, it would retain, with increased tenacity, its electrons and prevent their escape under conditions in which a neutral atom would be ionised.

In this again, the want of knowledge as to the nature of the positive charge of the atom renders the matter very obscure.

68. The β rays.—The cases in which atomic disintegration is distinguished by the emission of electrons with very high velocities are not so numerous, the only instances at present known being certain active products. Of the radium series Ra. C is the most conspicuous case, but β rays are also emitted by Ra. F and, as recently discovered, by Ra. B also.

It is evident that Ra. C must be regarded as a special

example of atomic instability, for not only are electrons emitted with exceedingly high velocities but the α particles from this product have the greatest ionisation range (7·06 cms. in air).

As the ionisation range of an α particle is indicative of its initial velocity, the disintegration of the atom of Ra. C must be accomplished with unusual violence.

69. Power of Penetration.—The power of penetration possessed by an electron moving with very high velocity is explained by its minuteness considered in connection with the fact already mentioned, namely, that the open spaces within the system of an atom are relatively enormous. It appears most probable that an electron passing through matter experiences nothing of the nature of an impact; the only opposing force seems to be the repulsion of the electrons within the atomic systems which lie in its path, and the effect of an encounter would be to alter, to some extent, the direction of motion.

The power of an electron to resist such tendency to alter its direction of motion may be considered as being proportional to its velocity. It seems probable that the effects of an encounter are determined by the relative velocities of the electrons performing orbital motions within the atom and the electron which is passing through the system, and that unless the velocity of the latter is very great, it would tend to follow a series of very short curved paths while passing through matter.

The fact that there is experimental evidence that the β rays are scattered after passing through matter may be taken as supporting this idea, for it is clear that most of the electrons would be following paths inclined at various angles to their original direction of motion at the moment of emergence.

70. Variation of $\frac{e}{m}$ of an Electron with its Velocity.—One of the most interesting facts about the electrons projected from the radio-active elements, is the proof which they afford of certain theoretical views set forth in a paper by Prof. J. J. Thomson in 1881. In this paper it was shown that a charged sphere in rapid motion would possess additional inertia due to its charge, which means that an electric charge in motion, itself possesses inertia and simulates the most fundamental property of matter.

If then a charged sphere be moving with a high velocity, it will behave as if its mass is increased, but this increase of mass is absolutely insignificant unless the velocity is comparable with that of light and the potential of the charge is very high, which latter condition would be fulfilled for a given charge by its concentration on a small enough sphere. The mass of a moving charge has been conceived as due to the bound ether carried along by the system of lines of force having the charge as their centre, the electric being radial and the magnetic, concentric and circular, with their planes at right angles to the direction of motion.

Before the discovery of electrons, there were no electrified bodies known which were either sufficiently minute or possessed of a high enough velocity to supply a means of experimentally observing the increase of mass expected from theoretical reasoning. The electrons emitted by radium, however, (by reason of the products B, C and F) have velocities approaching, in some cases, the velocity of light itself, and they are also electrified bodies far more minute than any atom.

It appeared that, as the charge of an electron is always

constant, a variation of the value of $\frac{e}{m}$ with velocity might be possible of experimental detection. This delicate investigation has been undertaken with great success by Kaufmann, who has determined the value of $\frac{e}{m}$ for electrons with varying velocities. The results are in wonderful agreement with theory, and show that the mass does actually increase with velocity, although a fairly close approach to the velocity of light is necessary before this increase becomes very appreciable. Thus if the mass of a slowly moving electron be taken as unity, it is represented by 1·12 at one-half, and by 3·28 at 99 per cent. of the velocity of light. Beyond this the increase of mass becomes rapid, and would be theoretically infinite at the velocity of light itself.

The decreasing value of $\frac{e}{m}$ with increasing velocity is best illustrated by the following figures taken from those given by Prof. Thomson in his work "Electricity and Matter."

v.	$\frac{e}{m}$.
2·36	1·31
2·59	0·975
2·83	0·62

Prof. Thomson has calculated the ratio of the masses of electrons moving with high velocities to the mass of an electron at rest, on the assumption that the *whole of the observed mass is due to the electric charge*, and has compared his results with the same ratio deduced from the experimental investigations of Kaufmann. The

values of this ratio for the same values of v are here given.

v.	Calculated value.	Experimentally determined.
2·36	1·50	1·65
2·59	2·00	2·04
2·85	3·10	3·09

The close agreement can only be regarded as wonderfully significant in support of the electrical theory of matter, for it indicates that an electron cannot be regarded as having any material nucleus, but must be considered as pure negative electricity.

It may thus be that the mass of an atom is determined by the velocities of its component electrons, and the same reasoning will therefore be applicable to matter as a whole, in which case the property described by the word "mass" is due to the bound ether carried by an immense number of electric charges in motion, mechanical inertia and electrical inertia being identical in character.

Until much more is known about the atom, it is impossible to regard these ideas as more than very reasonable theoretical conceptions, but the whole range of known phenomena which must be included in any theory that can claim to present a true and comprehensive explanation of the facts, is so vast that the matter is one of extreme difficulty. There is, however, every reason to be more than satisfied with the marvellous advance made by science in the investigation of the mystery of matter, and the conceptions introduced are far more acceptable and reasonable than any idea implied in the words "ordinary matter," an expression which, scientifically speaking, cannot be said to have any meaning. The question is one of extreme interest, but it need not be

considered in any detail here as it is not essentially connected with the subject of this book.

71. The γ rays.—An electron moving with uniform velocity carries with it a steady magnetic field. A variation of this field constitutes a form of radiation, and can only occur as the result of accelerated motion, but this does not necessarily imply an actual change of velocity; variation of *direction* of motion also being considered as a form of acceleration. The fact that γ radiation is emitted only from the products giving β rays, suggests that the γ ray is the resultant pulse set up by the acceleration of the electron as it leaves the atom.

The great power of penetration possessed by the γ rays indicates that the acceleration is very violent and gives rise to a pulse-shell of extreme thinness, and it seems an open question whether the acceleration due to change of direction of motion is alone competent to produce this result, or whether it is necessary to assume that the electron also experiences an actual positive acceleration in escaping from the atomic system.

In any case it is clear that the acceleration is far more rapid than can be artificially produced in a vacuum tube for the generation of X rays.

72. Ionisation.—Owing to the violence of the γ-ray pulse, it possesses a considerable inductive power to which must be attributed the ionisation set up by the passage of the radiation through gases. The electrons which are in association with the gas atoms receive a powerful side-thrust on the arrival of the pulse which, in some cases, is sufficient to separate them from the atom altogether, thus forming negative and positive ions.

73. Secondary Radiation.—The secondary radiation set up by the impact of radium rays on matter consists

largely of electrons projected with varying speeds, and its exact explanation is a matter of some difficulty. It appears, however, that an actual disintegration of an otherwise stable atom can be brought about by the incidence of the β and γ rays, and that the emitted electrons are to be regarded as having been expelled from the atoms of the matter acting as radiator. On this view, secondary radiation is an artificially produced radio-activity strictly analogous, while it lasts, to the natural activity of the radio-elements, and the action of the primary radiation is to be considered as instrumental in calling into evidence the inter-atomic energy of normally non-active matter.

The secondary radiation of a non-particulate nature which has also been observed, is explicable in exactly the same way as γ radiation, and must be assumed to be due to the acceleration of the emitted electrons, but the possibility of such a form of radiation arising directly from the impact of primary β rays on matter must also be remembered, and the probability is that both causes combine to produce the observed effect.

74. Fluorescence.—Certain substances which glow with a distinct and characteristic luminosity when stimulated by various forms of radiant energy are said to be fluorescent. In nearly every case the light emitted is less refrangible than the radiation which causes it, but there are a few exceptions.

It has been stated that, in addition to the action of electro-magnetic radiation, fluorescence is caused by the particulate rays of the radio-active elements, and in both cases similar theoretical conceptions are introduced.

Knowing that radiation is the result of acceleration of electric charges, it is necessary to conceive that, in

connection with the molecules of fluorescent substances there are certain electrons or electron systems in more or less unstable equilibrium, and that the disturbance caused by the impact of particulate rays (α particles or electrons) is sufficient to cause them to become sources of radiation. It is very necessary to distinguish between the conception of fluorescence and the emission of light by reason of elevation of temperature; that is to say, between fluorescence and incandescence.

The processes involved in the production of incandescence must be regarded as being, to a great extent, indirect. In this case the free electrons contained in the body become agitated by the incidence of radiant heat and, in turn, communicate motion to the atoms, which become sources of radiation when the disturbance is violent enough to affect their electron systems; the last stage being marked by the disappearance of the continuous spectrum and the production of the spectrum lines indicative of the gaseous state. The elevation of temperature due to the agitation of the atoms by mechanical shock is explicable in the same way—in each case luminosity is arrived at through, and maintained by, the medium of heat.

Any means of *directly* disturbing the electron systems responsible for radiation, will result in the production of luminosity without the necessity of a corresponding elevation of temperature. This is the process of ordinary reflection of light, whether general or selective, matter becoming vividly luminous with a very small elevation of temperature unless the visible rays are also accompanied by considerable radiant heat. To this extent fluorescence may be compared with reflection, but the important difference between the two cases is that, while ordinary substances can only emit light which is incident

on them, that is to say, reflect it, fluorescent substances emit light which is quite different to the incident radiation. In illustration of this the cases may be mentioned of fluorescein which glows a brilliant green when stimulated by only violet and ultra-violet rays, and barium-platino-cyanide which emits light of a very similar colour when exposed to X rays.

Of compounds which fluoresce when stimulated by particulate radiation, zinc sulphide and the mineral willemite have already been mentioned.

It is obvious that a peculiar and sensitive electronic constitution must be a characteristic of the molecules of all fluorescent bodies in order that they should be directly responsive in a perfectly definite manner to such widely varying agencies. The term "phosphorescence" is applied to substances which continue to emit light for an appreciable time after the removal of the exciting cause, and in such cases the disturbance set up in the electrons affected takes a considerable time to subside—calcium sulphide, specially prepared, is an excellent example of this action, showing luminosity for hours after exposure to light.

Fluorescent substances may be considered as providing a means for transforming the frequency of radiation, and in this capacity they have been of invaluable service in the detection and investigation of forms of radiant energy to which the eye is not sensitive. The property is exhibited by substances having a very wide range of chemical composition, but it seems to be almost exclusively confined to compounds, the diamond being, perhaps, the only instance of fluorescence exhibited by any form of an element, and even in this case the property is very variable in different varieties, and may be due to some impurity.

75. Scintillations produced by the α rays.—Some very interesting theoretical conceptions are introduced by a consideration of the action of the α particles on fluorescent compounds, especially on crystalline zinc sulphide which is nearly always used to show the scintillations.

It is clear that if the disturbance created by the impact of an α particle were strictly confined to the molecules lying in its path, the effect would be quite inappreciable. The scintillations are so bright and definite that it is hard to keep in mind an adequate idea of the extreme minuteness of the particles responsible for their production.

The fact that a scintillation is so readily visible shows that it must proceed from an area which is enormous in comparison with the size of the incident α particle, and it appears certain that the disturbance created is felt for a very considerable distance around the point of impact. Observations of the scintillations produced by crystalline fragments of varying degrees of fineness point to the conclusion that the disturbance is probably communicated throughout the volume of the fragment struck, and the resulting scintillation is due to the fluorescence set up throughout this same volume. This effect could be explained by supposing that the impact of an α particle produces an electric pulse which is communicated to the responsive electrons around the seat of disturbance and affects them in inverse proportion to their distance from it. In support of this conception, the action of the α rays on diamonds may be mentioned. Different specimens of the diamond vary in sensitiveness, but a fairly large stone will sometimes show nothing but a continuous glow under the action of the α rays from radium

If the disturbance were confined to the immediate vicinity of the point of impact, the face of the stone should always show a distinct scintillating appearance when viewed with a lens, provided the incident α particles were not excessively numerous, and the fact that such an action is not invariably observed, seems to prove that the disturbances are able to travel out from the points of impact and tend to fill the volume of the crystal.

The fact that there is this relatively enormous volume for the disturbance due to each α particle to fill would, of course, render their individual action too scattered and faint to be recognised, the steady glow being the total effect of all the α particles incident on the diamond at any given instant.

The effect of employing very small fragments of a fluorescent compound seems to be to confine the energy within the limits of volume of the fragment struck so that its total momentary luminosity is visible as a scintillation.

A screen coated with diamond fragments is thus able to show the scintillating action well, for the disturbance appears to be intense because limited to a small volume. An analogy illustrative of the supposed action is provided by scattering a handful of small pebbles into a pond in the one case, and into a collection of small pools in the other. The ring-waves (neglecting the time they take to travel) will each separately cover the whole surface of the pond, whereas in the second case, their action is localised to the area of the various small pools.

There have been various other theories which have been suggested in explanation of the α ray scintillations. It has been suggested that they are the result of the recombination of ions formed within the crystal, but if

this were so, it might be expected that scintillations would be visible in a wide range of crystalline substances.

Another suggestion is that the flashes are due to fractures of the crystals, for it is known that zinc sulphide is very sensitive to mechanical shocks. It seems, however, absolutely impossible that an α particle could produce such a fracture, having regard to its size, which is minute even in comparison with a molecule.

Any conception which regards the action as strictly confined to the path of the α particle, appears insufficient to explain the facts, as the number of molecules which would be traversed, although large, is nevertheless inadequate to provide the intensity of fluorescence observed.

76. Duration of a Scintillation.—The scintillations seen in the spinthariscope appear as instantaneous flashes of light, but no idea is conveyed of their extremely short duration. An estimate of the duration can be arrived at by using a screen moving with considerable velocity in its own plane. If this velocity is sufficient to move the screen by a perceptible amount during the time occupied by a scintillation, the latter will appear, not as a sharply defined luminous point when viewed in a darkened room with a lens, but lengthened out into a luminous trail. The velocity necessary to produce any appreciable effect on the appearance of the scintillations is very considerable, and would indicate that the actual duration is of the order of $\frac{1}{50,000}$th of a second!

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77. Radium Emanation.—The gaseous nature of the emanation of radium having been recognised, it became a matter of importance to determine its chemical properties. On the disintegration theory, the emanation is to be considered as a new elementary form of matter and, as such, it might be expected to give evidence of the possession of definite properties which would assign to it a place in the periodic law.

In order to decide this question, the emanation has been brought into contact with a number of reagents under widely varying conditions of temperature, but in no case has the slightest evidence of chemical affinity been detected, the emanation passing absolutely unchanged through the most drastic chemical operations.

This result is very significant as to the true nature of the emanation, for absence of all affinity is the distinguishing characteristic of the gases of the argon family, and to this group of non-valent elements the emanation apparently belongs. It seems certain that, if the emanation had any valency, it must have been detected under the conditions of experiment.

Knowing that the atom of emanation results from the disintegration of the radium atom, its atomic weight is probably nearly equal to that of radium for, neglecting the possibility of reduction by the repulsion of electrons with low velocities, the only loss sustained by the radium

atom previous to the formation of the atom of emanation, is represented by the mass of the α particle.

This would place the emanation considerably below xenon in the zero group of the periodic law.

78. Volume of the Emanation.—The volume of the emanation from radium is always exceedingly minute, but its amount can be deduced from calculation. The volume obtainable from one gram of radium bromide in radioactive equilibrium is given as $4{\cdot}6 \times 10^{-4}$ c.c. (at atmospheric pressure and temperature) by Prof. Rutherford, which means that the volume produced by one gram of radium is about 0·82 cubic millimetre assuming that the bromide has a formula $Ra.\ Br_2$.

This calculated volume is sufficient explanation of the fact that all the earlier attempts to experimentally observe and measure the volume of emanation were unsuccessful. More recent attempts with relatively large amounts of radium, however, have shown that it is possible to obtain the emanation in sufficient quantity to observe its volume. The necessary isolation of the emanation from all other gases is a matter of no small difficulty, but the experiment has been performed by Sir W. Ramsay and Prof. Soddy, who arrived at a result in close agreement with the calculated volume, their determinations giving a value of one cubic millimetre per gram of radium.

79. Luminosity of the Emanation.—In all experiments with the emanation derived from comparatively large quantities of radium, the passage of the gas through the glass tubes of the apparatus used can be followed by its luminosity which becomes bright when the emanation is condensed by the action of extreme cold or compressed within a small volume. This luminosity is possibly due to the action set up in the gas itself by its own radiation,

but a similar effect would be produced on any inactive gas with which the emanation was mixed. In the case of air, the luminosity is probably identical with that observed in the case of a radium salt, which was shown to be due partly to the action of the rays on the nitrogen of the atmosphere.

80. Action in an Electric Field.—Observations of the action of an electric field on radium emanation show that it is attracted by the negative electrode, indicating that its atoms are positively charged. If a wire is maintained at a negative potential and exposed to the emanation, it becomes highly radio-active owing to the deposition of most of the emanation upon it, and the consequent formation of the active disintegrated products.

81. Spectrum of the Emanation.—Strong evidence of the elementary nature of the emanation is afforded by the fact that it emits a distinct spectrum. Attempts to observe the spectrum revealed the existence of several bright lines, and Sir W. Ramsay and Prof. Soddy later succeeded in obtaining the spectrum of the emanation for a sufficient time to accurately observe its character and make a determination of the wave-lengths of the conspicuous lines. The general character of the spectrum was indicative of the non-valent gases, and gave additional support to the view that the emanation falls in the zero group.

82. Radium Emanation and the Production of Helium.—Owing to the intense radio-activity of the emanation, it quickly decays into the first solid product Ra. A, the process of disintegration of the emanation atoms being marked by the emission of α particles.

The true nature of the α particle is one of the most interesting and important questions in the science of

radio-activity at the present time, and several physicists are making it a special object of investigation.

If the α particles emitted by the emanation are the atoms of any gas, its gradual production during the period of decay of the emanation should be capable of detection by the spectroscope although, on account of the high velocity with which the α particles are projected, a large proportion of the total number may become occluded in the glass of the sparking-tube used in the observation of the emanation spectrum.

A fact which is very suggestive of the possible nature of the α particle is that the chemically inert gas helium is invariably found occluded in radio-active minerals. The mass of the α particle, as calculated from observations of the magnetic deflection, indicates that it has a mass intermediate between that of the atoms of hydrogen and helium but, owing to the great experimental difficulties involved in this determination, the result must not be taken as necessarily strictly accurate. The value obtained is on the assumption that the positive charge of the α particle is equal to that of the hydrogen ion, and the discovery of any inequality would affect the estimated mass.

Assuming the correctness of the idea that the charge is equal to that of the hydrogen ion, it is still by no means certain that the α particle is not a helium atom.

In 1903, Sir W. Ramsay and Prof. Soddy undertook the experimental investigation of the question with the hope of obtaining some spectroscopic evidence which would throw light on the problem of the possible identity of the α particle and the helium atom.

A very careful spectroscopic observation was made of the emanation after it had been isolated from other gases,

(principally hydrogen and oxygen resulting from the solution of the radium salt in water,) and a bright yellow line was detected which proved to be coincident with the D_3 line of helium.

Later experiments with the emanation derived from larger quantities of radium resulted in the recognition of the complete helium spectrum after an interval of a few days.

The importance of the experiments lies in the fact that the helium spectrum was not initially present, but only appeared after a considerable interval, proving that there was no helium originally present with the emanation, and that it must have resulted from the disintegration of the emanation atoms.

The spectrum which first appeared was a new one and was taken to be that of the emanation itself. This new spectrum gradually faded while the brightness of the helium lines increased.

The experimental details in these observations necessitated the greatest possible care, the isolation of the emanation from all other gases being essential in order that their spectra should not mask the effects to be observed.

It is impossible to emphasise too strongly the importance of these results, which amount to nothing less than positive evidence of the birth of one of the recognised chemical elements.

The fact that helium results from the disintegration of the emanation does not necessarily prove the identity of the α particle with the helium atom, although it appears, at first sight, the most natural conclusion. It seems certain that helium cannot occur anywhere in the series of active products, for not only is it a gas under

all known conditions, but it is also of small atomic weight and not possessed of any discoverable radio-activity. Its inclusion in the series is impossible on account of its small atomic weight alone, for the radium products result from the gradual reduction of the radium atom by the emission of particulate radiation, and the appearance of the helium spectrum within an interval equal to the period of the emanation proves that it must result directly from the decay of the latter, and cannot possibly be considered as a final product occurring after the products of slow transformation. There is, on the contrary, every reason to believe that the final inactive product coming at the end of the radium series is still of high atomic weight, probably about 205.

83. Connection between the Physical Condition of the Emanation and the Gas evolved.—Sir W. Ramsay has recently made some very important experiments with radium emanation under modified conditions, and has found that when the emanation is in solution in water, the gas evolved by its decay does not appear to be helium but neon, another member of the group of non-valent gases.

This result seems opposed to the view that the α particle is a helium atom for, assuming the disintegration of the emanation to be accompanied by the emission of α radiation in the recognised way, the helium spectrum might still be expected to manifest itself.

Further modification of the conditions under which the decay of the emanation took place was brought about by its solution in water together with a salt of copper, and in this case the observed spectrum gave evidence of the production of argon.

The gases of the zero group are as follows :—

Element.	Symbol.	Atomic weight.
Helium	He.	4·0
Neon	Ne.	19·9
Argon	Ar.	38·0
Krypton	Kr.	81 8
Xenon	Xe.	128·0

The addition of radium emanation to this group seems now quite justified.

The periodic law suggests that a definite atomic structure is a characteristic of the elements of the same group, and this view is emphasised by a consideration of the electron theory of the atom. Assuming, from the appearance of its spectrum and absence of chemical affinity, the inclusion of the emanation in the zero group, it might be expected that the characteristic atomic structure of the members of this group would possibly be found in one of the atoms resulting from the disruption of the emanation atom, and the fact that different members of the group appear to be evolved under the varying physical conditions in which the disintegration of the emanation occurs seems to support this idea.

There are various theoretical considerations suggested in explanation of the evolution of neon and argon.

Firstly, it may be supposed that the atom of the emanation, *before* the time of its own natural disintegration, suffers disruption by the energy given out by the neighbouring atoms which are following the recognised series of changes, one of the products of this premature dissolution being an atom of neon.

This represents the case when the emanation is in solution in water. It is clear that the remainder of the emanation atom resulting from this process cannot be an

atom of the product Ra. A, but must be an atom of some unknown form of matter which may or may not be radio-active.

Secondly, it is possible to assume that the atoms of the emanation disintegrate naturally but in a different manner to the ordinary series of changes. The α particle expelled in this case may be an atom of neon. This would leave a new product strictly analogous to Ra. A, but not identical with it, being necessarily of lower atomic weight, as the emanation atom would have lost a mass equal to the atomic weight of neon (19·9).

Similar considerations would apply, with the necessary modifications, to the production of argon in copper solutions.

Until much more is known about the matter, it seems impossible to arrive at the true theoretical explanation of the observed facts. If the first supposition be correct, the helium spectrum might also be expected to result from the emanation atoms which were following the usual disintegration process.

The emission of α radiation is not confined to the emanation of radium but, on the contrary, is the most distinguishing characteristic of the radio-active elements and most of their active products, and it appears necessary to assume that, either all α particles are helium atoms and, therefore, that helium is evolved from nearly every form of active matter, or that the α particles emitted by one element or product are not necessarily identical with those emitted by another, and may differ fundamentally in atomic structure. If all α particles are helium atoms, no importance can then be attached to the idea that helium is evolved from the emanation *because* the atom of the latter has the distinguishing structure of

the atoms of members of the zero group, a structure which is found in the particle it projects before, or in the process of, its internal rearrangement into the atom of the product Ra. A.

The difficulties of the case may be to some extent overcome by assuming that the atom of radium emanation, in the course of its normal disintegration, breaks up into *two* systems *in addition* to the α particle expelled in the process, and that one of these systems is an atom of helium and the other an atom of Ra. A. This involves also the supposition that the helium atom is not projected with a velocity sufficient to cause ionisation, but merely evolved as a secondary product, the existence of which can only be discovered spectroscopically when the accumulated amount is sufficient.

When the physical conditions of disintegration of the emanation atom are modified by the proximity of water molecules, or to some condition depending thereon, the atoms evolved are those of neon and a new product analogous to Ra. A, which would be the first of a possible new series of active products. The α particle would also be emitted during this change in the usual way.

A similar process will occur in the case of the evolution of argon with the exception that the resulting product corresponding to the normally produced Ra. A will again be different.

This view is, of course, purely hypothetical, but it does not seem to offer the difficulties of the two previously mentioned, and it suggests the interesting possibility of the formation of new series of active products by the variation of the physical conditions in which the spontaneous disintegration of the emanation takes place.

Whether or not it presents anything like the true explanation of the complex phenomena involved can only be decided by future research.

The formation of theories in explanation of observed facts is not only permissible but often helpful and necessary, although such theories should be only lightly and provisionally adhered to until they are established by direct evidence.

In the case of these recent observations, the true processes are at present very obscure, and their elucidation will necessitate much delicate experimental work.

As the expression "radium emanation" is somewhat lengthy, the suggestion was made by Sir W. Ramsay that such gaseous forms of active matter should receive names expressive of both their nature and origin, and with this view the terms "exradio," "exthorio," etc., have been introduced and are sometimes used.

VII

84. Radio-active Transformations of Thorium.—Although thorium has an activity very much less energetic than that of radium, it is nevertheless a highly interesting element, and one which has been extensively studied. In many respects thorium is analogous to radium, evolving an active emanation which, in turn, gives rise to a series of disintegration products.

It was early discovered that the evolution of the emanation was not the direct result of the disintegration of the thorium atoms, but that a solid product first made its appearance which could be separated from thorium by chemical means. This product is known as thorium X, and has already been mentioned.

For a long time it was thought that the atom of thorium X represented the first system resulting from the instability of the thorium atom itself, but recently it has been shown that two intermediate products exist which have been named meso-thorium and radio-thorium respectively.

The gaseous emanation thus represents the fourth stage in the process of the reduction of the thorium atom.

The thorium series according to Prof. Rutherford is here given :—

Active substance.	Period.	Radiation emitted.
Thorium (at. wgt. 232)	10^{10} years	α particles
↓ Meso-thorium	?	β particles, γ rays
↓ Radio-thorium	800 days	α particles
↓ Thorium X	3·7 days	α particles
↓ Thorium emanation (gas)	54 seconds	α particles
↓ Thorium A	11 hours	(rayless change)
↓ Thorium B	1 hour	α particles
↓ Thorium C	?	α and β particles, γ rays
↓ ?		

85. Thorium Emanation.—With regard to the absence of all chemical affinity, the emanation of thorium behaves in exactly the same way as that of radium. Experiments with many reagents were carried out by Profs. Rutherford and Soddy and clearly demonstrated its chemical inertness.

For this reason thorium emanation must also be regarded as belonging to the zero group and, although three products come between thorium and its emanation, the atomic weight of the latter is probably higher than the corresponding emanation of radium. As, however, the quantities of both emanations are so minute, there is only indirect evidence on this point.

In the case of thorium, the amount of the emanation is inconceivably small, and its volume is quite beyond

experimental detection even when large quantities of thorium compounds are available.

This is due to the fact that thorium has only a very feeble activity and the emanation a rapid period of decay, for it is evident that the number of emanation atoms formed in a given time is determined by the number of thorium atoms undergoing disintegration, although three products intervene, from the last of which the emanation is directly evolved. Thorium is thus able to maintain only a very minute equilibrium quantity of its emanation.

The condensation of thorium emanation apparently occurs at a somewhat lower temperature than that necessary in the case of the emanation of radium, the value arrived at being $-120°$ C.

The behaviour of thorium emanation in an electric field shows that it is attracted to the negative electrode, its deposition on which is rendered evident by its radio-activity. In this respect the action is precisely similar to that observed in the case of radium emanation, and indicates that the atoms are positively charged.

86. Active Products.—Prof. Rutherford points out that in the products meso- and radio-thorium, physicists have at their disposal two forms of matter possessing a high radio-activity and fairly long periods, one emitting β and γ radiation and the other α rays; and that as thorium is used commercially on a large scale, it may be possible to obtain these products from it at a moderate cost.

The period of meso-thorium is not known with any certainty, but it seems clear that it is longer than that of radio-thorium.

In the case of Th. C the disintegration of the atomic system evidently takes place with considerable violence, as all three types of radiation are emitted. The period

of this product is not known, and its decay seems to be followed by the formation of a product which is either inactive or possessed of a very long period, but the similarity of atomic instability in this instance to that presented by the product C of the radium series is to be noted.

It appears probable that thorium, in the course of its radio-active changes, also evolves helium, but the evidence on this point is indirect, and cannot be considered as conclusive.

87. The Radio-Activity of Actinium.—An investigation of the activity of actinium has shown that this element also gives rise to a series of active products. The most recent work on the subject has proved that the actinium atom passes through at least five successive stages of instability before the formation of a final product, the transformations being given thus :—

Active substance.	Period.	Rays emitted.
Actinium . . .	?	Rayless change
↓		
Radio-actinium . .	19·5 days	α particles
↓		
Actinium X . . .	10 days	α particles
↓		
Actinium emanation (gas)	3·7 seconds	α particles
↓		
Actinium A . . .	34 minutes	Rayless change
↓		
Actinium B . . .	3 minutes	α and β particles, γ rays
↓		
?		

It will be seen from the above that, like radium and thorium, actinium evolves a gaseous emanation, and there is a strong probability that this emanation is also a member of the zero group of non-valent gases. Owing to the extremely short period by which this emanation is characterised, it is a matter of great difficulty to investigate its properties and, for the same reason, its equilibrium amount is also excessively small.

The emanation of actinium supplies a most interesting example of atomic instability, possessing a period shorter than that of any other known form of radio-active matter.

In the cases of thorium and actinium, as with radium, the disintegration products exist in quantities far too small to be directly appreciable, and can only be investigated by tracing their activity through different chemical operations.

It will be noticed that all the products of actinium have comparatively short periods. That of actinium itself is not known, but it is evidently very long.

A direct determination of the velocities of the α particles or electrons emitted by forms of matter of feeble activity has not been found possible, but an estimate can often be made in the case of the α particles by observation of the ionisation range, and in the case of the electronic β rays, by their power of penetration.

The β radiation from Act. B appears to be very homogeneous, indicating that the electrons are expelled with nearly equal velocities.

VIII

88. The Origin of Radium.—The latest determinations indicate that radium has a period of about two thousand years, and it is thus evident that all the radium at present existing must be in slow transformation into other forms of matter, a transformation which will be practically accomplished in a few thousand years.

Such a period is very short in comparison with geological epochs, and the fact that radium occurs in pitch-blende and various other ores indicates that it must itself be constantly evolved from some source.

The distinguishing feature of all radio-active processes is their absolute constancy, and it is certain that the radium now present in the world could not have been in existence thousands of years ago.

The thought suggests itself that possibly radium is a disintegration product of some element having a comparatively small radio-activity and an exceedingly long period. It is obvious that such an element must also be of a higher atomic weight, and the only elements known which fulfil the necessary conditions are uranium and thorium. Various considerations are in favour of uranium being the parent element of radium. This element presents a simpler case of radio-active transformation than thorium and, until recently, only one active product was known namely, uranium X which has a period of twenty-two

days. Uranium thus differs from radium, thorium and actinium in not giving rise to any gaseous emanation.

89. Uranium in Relation to Radium.—Of the three types of radiation emitted by uranium, the α rays arise from the element itself and β and γ rays from its product uranium X, the disintegration of which appeared to evolve some inactive form of matter.

The transformations are thus given :—

Element.	Period.	Rays emitted.
Uranium (at. wgt. 239) . .	5×10^9 years	α particles
↓		
Uranium X	22 days	β particles, γ rays
↓		
?		

It is clear that if radium stands in genetic relation to uranium, it should occur associated with uranium as a disintegration product provided a time is allowed sufficiently long for its accumulation in detectable quantity.

It was pointed out that minerals containing uranium should also contain radium and that, as such minerals are probably extremely old, the radium should be found in its equilibrium amount, the proportion between the two elements being constant for different minerals. It is significant that radium always occurs associated with uranium in pitchblende and other uranium minerals. Various delicate experimental tests have been made to determine whether any constant relation exists between the amount of uranium and radium in many different

varieties of radio-active minerals, and these have resulted in strong evidence in favour of the idea that radium is actually evolved from uranium.

A method which has been largely employed in such research is that of estimating the quantity of radium by means of the emanation evolved by the mineral on chemical treatment. The results obtained are in fairly good agreement with the proportions calculated from the theoretical consideration of radio-active processes.

The proportion between uranium and radium has been found to be a definite constant for minerals from many different parts of the world, the quantity of radium per gram of uranium being $3{\cdot}8 \times 10^{-7}$ grams.

The delicacy of the electrical method of investigating the radiations from radio-active elements is so great that, assuming that radium is evolved directly from Ur. X, its production in a compound of uranium initially freed from all trace of radium should be capable of detection in the comparatively short period of a few months.

This has been made the subject of some exceedingly delicate tests, but in each case evidence of the actual production of radium was extremely doubtful, and it seemed certain that, if radium were present at all, it existed in a quantity less than $\frac{1}{1000}$th of that to be expected from theory.

This apparently negative evidence has been explained, however, by assuming that one or more products of slow transformation exist between Ur. X and radium. In the case of uranium minerals, the period is amply sufficient for the condition of radio-active equilibrium to be reached even if the intervening products have very slow transformations, and this would explain the constant relation found.

If these hypothetical products emit particulate radiation, their presence in radio-active ores should be capable of detection, and in this connection actinium is suggested as the possible parent element from which radium is evolved.

The gradual production of radium in a preparation of actinium has actually been observed, and it thus appeared that radium resulted from the disintegration of the atoms of the product Act. B, and that the actinium series occurred between Ur. X and radium. It was proved by Prof. Rutherford, however, that the radium did not result from actinium, but from some hitherto unknown element which was extracted with it and was present as an impurity.

This new element has been called "ionium" and its existence has been confirmed.

In its general properties ionium appears to resemble thorium, but as yet not very much is known about it.

There is thus evidence of the existence of a consecutive series of products extending from uranium to the final product of radium, the link between Ur. X and radium being supplied by ionium—

Element .	Uranium	→ Ur. X →	Ionium →	Radium → etc.
Period .	5×10^9 years	22 days	?	2000 years
Rays emitted	α rays	β and γ rays	α rays	rays

In the opinion of Prof. Rutherford, uranium and thorium are to be considered as two independent elements, but actinium as an alternative product of Ur. X—a sister element to ionium, in fact.

On this view, two different formations are possible in the electron system of the atom resulting from the disintegration of the atom of Ur. X, one of them representing the atom of ionium, and the other the atom of

actinium. The constant proportion which has also been found to exist between the amounts of uranium and actinium in radio-active minerals receives explanation on this assumption.

An analogy to this alternative electron formation of the atom is provided by the floating magnetic needles, certain numbers being capable of taking up two different configurations, one rather more stable than the other.

The more usual result of the disintegration of the atom of Ur. X appears to be the formation of an atom of ionium, but it is thought that a certain proportion give rise to the formation of the alternative system representing the actinium atom.

90. Final Product of Radium.—The question as to the final disintegration product of radium is of much interest. It is evident that such a product, not being appreciably radio-active, must be a stable element, the accumulation of which in radio-active minerals should be capable of detection by ordinary chemical means. Pitchblende contains small quantities of many elements, one of them being lead.

If lead is the final product of the radium series, the quantity of lead in uranium minerals should bear a constant proportion to the amount of uranium contained, assuming that it is not simultaneously evolved from some independent source. There is some evidence that a constant relation exists between the amount of helium occluded in radio-active ores and the amount of lead also present, and as helium apparently results from the disintegration of the atoms of the radio-elements or their active products, the constant proportions in which helium and lead occur is very suggestive that the latter may be the final product evolved from Ra. G. The possibility of

an alternative final product must however be remembered. Assuming that the α particle is in reality a helium atom (at. wgt. 4), the loss of five α particles would suffice to reduce the atomic weight of radium to that of lead ($226{\cdot}5 - 20 = 206{\cdot}5$), and an examination of the radium series will show that radium itself and four of its products emit α particles. This assumption, however, leaves no room for the possibility of the emission of any form of α radiation in which particles have velocities below the critical ionisation value.

A theoretical knowledge of radio-active transformations has rendered possible certain calculations as to the rate of production of the various products, and a comparison of the values arrived at with the actual quantities of the constituents of radio-active minerals has resulted in some highly interesting estimates of their probable age.

As an example of this it has been found possible to calculate, on certain assumptions, the rate of accumulation of helium in the mineral fergusonite which contains about 7 per cent. of uranium. The volume of helium theoretically produced in one year per gram of fergusonite is given by Prof. Rutherford as $1{\cdot}3 \times 10^{-8}$ c.c. and the volume actually found per gram is 1·81 c.c. This indicates that, assuming the rate of production to have been uniform throughout the period, the age of this mineral is about 140 million years!

91. The Emission of Heat by the Radio-active Elements.—The heat emitted by radium has been proved to be a secondary effect due to the impact of the α particles with the substance of the radium itself. It is evident from this that all radio-active elements must, to a certain extent, emit heat, and a consideration of this fact leads to some very important conclusions.

A difficulty which has always confronted physicists is the estimated age of the earth. Geological and biological considerations demand a period far longer than was physically admissible on the assumption that the earth was a mass which was simply cooling down from an initially high temperature.

The recognition of the enormous force latent in the atomic systems of the elements has led to a considerable modification of previous views, and has shown that the radio-activity of certain forms of matter is competent to enormously extend the estimated age of the earth.

It has been calculated by MM. Curie and Laborde that one gram of radium emits 100 gram-calories per hour, from which it can be shown that the presence of a very minute quantity of active matter in the mass of the earth will suffice to so prolong the process of cooling as to amply satisfy the most extravagant demands of geologists.

The science of radio-activity also supplies the solution to the great question of the maintenance of solar radiation, and it has been calculated that the presence of 2·5 parts of radium in one million will account for the present rate of emission of energy.

Such possibilities have a profound astronomical significance, indicating almost limitless time for the processes of stellar evolution.

92. Radio-Activity of Matter.—It has been shown that radio-activity is an atomic property and that the elements in which it is manifested are, in every other respect, precisely similar to the recognised inactive elements. The question arises as to whether all elements are not radio-active to some very slight extent.

The rate of transformation of an element, that is to say its period, depends on the number of atoms which undergo

disintegration per unit time in a given mass. If the proportion which this number bears to the total number of atoms is relatively high, the period will be correspondingly short, but provided that the disintegration of the atomic systems is not marked by the emission of particles (either α particles or electrons) with velocities equal to the critical velocity of ionisation, the activity of the element would escape detection by the methods of investigation at present available. The only means by which such atomic instability might be recognised would be by the indirect evidence afforded by the gradual production of the disintegration product or products.

It is, however, quite possible that the so-called inactive elements represent atomic systems which are very stable. The proportion of these breaking up per unit time may then be really exceedingly small, indicating that these elements have enormously long periods. The activity of such stable elements, although possibly consisting of the emission of particles with velocities above that necessary for ionisation, would nevertheless be exceedingly difficult of detection owing to its feeble intensity.

Evidence has recently been obtained of the emission of α particles from many metals. That this α radiation is not due to some radio-active element present as an impurity, has been proved by the fact that a distinctive ionisation range characterises the α radiation from all the recognised radio-active products, the greatest being that exhibited by the radiation from Ra. C. Any α radiation, therefore, distinguished by a still longer ionisation range, cannot be attributed to the presence of a minute trace of radium or any other of the known radio-elements.

It is very probable that all the chemical elements are undergoing very slow transformation by reason of the

instability produced in their atoms by the emission of an exceedingly feeble electro-magnetic radiation which serves to gradually reduce the velocity of the electrons composing them until the critical velocity is reached, necessitating the rearrangement of the system.

93. Atomic Evolution and Disintegration.—So far then as the present means of investigation are concerned, the intensity of the radio-activity of an element must be regarded as depending on the number of α particles or electrons emitted above the critical ionisation velocity, and it is thus possible for a radio-active element like uranium to have a longer period than some of the elements which are now regarded as inactive.

It will be clear, from a consideration of the quantities in which radio-active products occur at their equilibrium values, that the scarcity of an element may be taken as a guide in the estimation of its probable period, the scarcer elements representing the most unstable forms. Such a consideration reveals a stupendous scheme hidden in the relations exhibited in the periodic law of the elements, and indicates that a process of elemental evolution and disintegration is perpetually in progress throughout the visible universe.

At the present time physical science is mostly concerned with the investigation of atomic disintegration, but there is reason to believe that the corresponding synthetical process must be in progress although, as yet, direct experimental evidence of this has not, apparently, been obtained.

The study of radio-active phenomena reveals the existence of an enormous amount of energy locked within the atom. At present no means is known by which this energy can be artificially liberated, except, perhaps, in

the case of the secondary radiation emitted by inactive matter under the action of primary rays.

94. Evidence afforded by Stellar Spectra.—One of the most interesting facts brought to light by research in stellar physics is that the spectra of stars are a guide to their temperature and that, in the stars of highest temperature, several of the known elements exist in a modified form, indicating that their atoms are in the process of formation. There is spectroscopic evidence that the elements of smallest atomic weight appear first, while the heavier elements are only met with in stars of lower temperature.

The dissociated elements, revealed by a modification of their normal spectra, are designated by the prefix "proto," as "proto-magnesium," "proto-iron," etc.

From this it seems that the more complex electronic systems, representing the atoms of the heavier elements, cannot exist at the enormously high temperatures found in many stars, their formation only resulting after a considerable reduction of temperature has been effected by radiation.

After existing for untold ages, and entering into, and being liberated from, numberless chemical combinations, they undergo spontaneous disintegration back into the simpler systems, perhaps into the free electrons from which they were originally formed.

A sublime scheme of inorganic evolution is thus unfolded, extending over a period of time compared with which the age occupied by organic evolution is but as a day to a century. Thinking over these things, it is, perhaps, possible to obtain some faint and fleeting comprehension of the grandeur of an eternal Kosmos.

PART III

I

95. Kathode, Canal, and X rays.—Experiments on the discharge of electricity through gases are always interesting, and this interest is intensified by the knowledge that their theoretical interpretation has prepared the way for the explanation of the spontaneous radioactivity of certain elements.

Many different varieties of vacuum tubes can be obtained which are designed to demonstrate the phenomena attending the discharge at various pressures, and also the properties of kathode and canal rays. Very beautiful effects are given by long tubes which are not exhausted to a very high vacuum. In these the discharge is marked by an exquisitely delicate glow extending throughout the length of the tube, the colour varying with the nature of the gas. These tubes are often made in elaborate patterns into which fluorescent glass is introduced, and it is to be noticed that the discharge follows the often very complicated curvature of the tube and, when the conditions of vacuum and electric current are suitable, the glow frequently exhibits a banded appearance.

These alternate zones of luminosity and comparative darkness are very striking, and are due to regions of active ionisation separated from one another by spaces in which the electrons are acquiring energy of motion under the

electrical potential before their velocities are again great enough to produce the ionisation marked by the next bright band.

Such tubes should be worked from a medium size induction coil, (one giving a 7 to 10 cms. spark is suitable,) a spark gap between metallic spheres being introduced in series, if necessary, as a resistance. If a good mercury exhaustion pump be available, the whole process of the discharge at different pressures, ranging up to the highest degree of vacuum in which it will pass, can be observed, and this is one of the most beautiful experiments which can be performed. For such a purpose, a plain tube fitted with a flat kathode plate is, perhaps, the most suitable.

At a fairly high vacuum, the kathode stream begins to make its appearance, this being shown by the fluorescence of the glass opposite the kathode plate and a general reduction of the luminosity within the tube. With a tube bent at an angle, the fact that the kathode rays travel in straight lines independent of the position of the anode is at once apparent.

96. Magnetic Deflection.—There are many different patterns of vacuum tube for showing the deflection of the kathode rays in a magnetic field, one of the best being a tube in which a fluorescent screen is placed at a very slight angle so that the rays, after passing through a narrow slit, are marked by a track of light on the screen. Any bending in a magnetic field is at once shown by the track becoming curved.

In other varieties the impact of the rays, after passing through a circular or rectangular aperture, is shown by a spot of light on a fluorescent screen placed at right angles to the direction of motion.

In moderate vacua, the velocity of the electrons forming the kathode stream is not very great, and a field of small intensity is sufficient to cause a very marked deflection.

The magnetic field is best obtained by using an electro-magnet rather than a permanent magnet, as the strength of the field can be varied without moving the poles. In order to effect this gradually, a variable resistance should be inserted in series with the magnet. The tube should be fixed in a firm stand, and inserted between the pole-pieces of the magnet in such a way that the strongest part of the field lies a little in front of the slit aperture through which the rays pass, and on the side remote from the kathode. The electrons which pass through the aperture thus enter the field directly between the poles, and are deflected into a curve bending away at right angles to the lines of force. The curve followed is not the arc of a circle unless the field is of uniform intensity in the region traversed by the rays. A curve approximating more nearly to a circular arc would probably be obtainable by the careful adjustment of the position of the kathode with respect to the poles of the magnet so that the rays pass through the region outside the intensest part of the field, the polarity of the magnet being such that the rays tend to describe a curve centred upon the magnetic axis of the field.

An electro-magnet of convenient power for showing the deviation of the kathode rays is one wound to about six or eight ohms resistance, the current being supplied by two 4-volt accumulators connected in series. The pole-pieces should be movable, and the distance between the coils variable by means of clamp screws attached to the coils through slots in a soft iron base.

In the case of a tube of comparatively low vacuum, the application of a magnetic field only causes the luminous glow to pass to one side of the tube at the strongest part of the field, beyond which it assumes its original course, the passage of the discharge being completed by the arrival of the electrons at the anode.

97. Kinetic Energy of the Kathode rays.—Although the kinetic energy of the electron of the kathode stream is small compared with that of an α particle, such a copious emission occurs from the kathode, that any solid object on which the rays fall is subjected to a very distinct push. This is well shown by a tube containing a vane, similar to that of a radiometer, so arranged that the kathode stream falls upon it. On passing a discharge through the tube the vane revolves rapidly. If the kathode plate be so placed that the electron stream passes away from the vane it will be unable, of course, to cause the latter to revolve, but the application of a magnetic field of suitable intensity and direction will curve the stream round on to the vane, which will then revolve so long as the field is maintained.

The effect is rendered additionally beautiful by coating the blades of the vane with various fluorescent compounds which become luminous under the impact of the rays.

98. Fluorescent Effects.—The property of the kathode rays of causing fluorescence has already been mentioned. Tubes containing various minerals and fluorescent compounds for showing this property are the most beautiful imaginable, and are made in great variety with many different substances. The vacuum is, in most cases, only just high enough for the production of the kathode stream, and several of these tubes can be connected in series and set in action with a moderately large coil. Care should be

taken that the total resistance is great enough to prevent the passage of too heavy a discharge, and also that the tubes are properly connected together so that the discharge in each case passes in the right direction. Neglect of this may spoil a good tube by over-heating or the lowering of the vacuum.

99. Thermal Effects.—Where the kathode stream falls on the glass side of the tube, a distinct elevation of temperature is noticeable, and this becomes especially marked when the rays converge by reason of being emitted from a concave kathode. If a tube be made having a concave kathode, and the rays made to converge on a platinum disc only when bent out of their normal direction by the application of a magnetic field, the effect of this concentration is clearly apparent, for, while the glass which receives only a diffused beam beyond the "focus" is scarcely warm, the metal may be considerably heated, and indeed, with a very heavy discharge, rendered red-hot.

With tubes fitted with an aluminium "window," the effects and properties of the kathode rays can be investigated outside the tube, and this is, in many cases, very convenient, but such tubes are exceedingly difficult to make and are not generally obtainable.

100. "Canal" rays.—A specially constructed tube is necessary for the proper projection of positively charged atoms from the anode in the form of "canal" rays. In such a tube the anode must be a flat disc placed opposite the kathode, the latter having an aperture in the middle through which the canal rays pass. The positive atoms acquire velocity under the influence of the electric field existing between the anode and kathode plates, and a large proportion of the total number pass through the aperture, continuing their course as a beam on the far side.

In order that the positive atoms which have passed through the aperture shall not have their velocity reduced by the electrostatic pull of the kathode, an earth-connected metallic screen which, of course, also has a corresponding aperture in it, is placed behind the kathode and effectually shields the canal rays from its action.

The canal rays can, to some extent, excite fluorescence in certain compounds, and the kinetic energy of the component atoms is evident by the rotation of a vane in the same manner as observed with the kathode rays.

Owing to the fact that the canal rays consist of the projection of positively charged atoms, the nature of the residual gas in the tube determines to a considerable extent the characteristics of the rays, the mass of the atoms varying, of course, with the gas in question, while the charge remains constant.

Although exceedingly interesting from a theoretical point of view, the canal rays are not capable of producing the striking effects observed with the kathode rays.

101. The X rays.—A comparatively slight X radiation is generated by the impact of the kathode stream on the glass of the tube, and its existence is best shown photographically. For experiments with, and demonstration of the properties of, the X rays, a small focus tube of the modern pattern is most suitable. As a considerable amount of light is given out by the tube when in action owing to the bright fluorescence of the glass, it should be enclosed within a thin wooden box, preferably blackened outside. The invisible radiation passes freely through the wood, and its properties of penetration, ionisation and fluorescent effects are readily investigated. As the radiation proceeds from the anti-kathode, care should be taken that the tube is placed within the box in such a

manner as to ensure the maximum radiation in the desired direction.

Very beautiful fluorescent effects can be observed in this way with a variety of compounds. Diamonds nearly always show a distinct fluorescence, and it is possible to distinguish between genuine and imitation stones by placing them side by side in the path of the rays. It should be remembered, however, that different stones vary in the intensity of their fluorescence.

The fact that the X rays arise from the negative acceleration experienced by electrons on impact with the anti-kathode (on the assumption of the ether-pulse theory), can be well shown by placing a small focus tube between the pole-pieces of an electro-magnet so that the line joining the poles passes just in front of the concave kathode. A fluorescent screen should be employed to observe the presence of the radiation, and some metallic object can be inserted in the path of the rays in order to give a definite shadow. The electro-magnet should have a variable resistance in series so that the strength of the field can be controlled at will. On exciting a weak field, the cone of kathode rays will be deflected to a small extent from its original position, and its apex will occupy a point on the surface of the anti-kathode disc a little to one side of the centre. The fluorescent screen, however, still glows brightly, showing that no appreciable variation of the X radiation occurs so long as the "focus" of the kathode rays occupies some point on the anti-kathode.

The strength of the field should now be increased until the kathode stream is drawn completely off the anti-kathode, and it will be observed that the production of X rays almost entirely ceases at the same instant, for the kathode rays, having nothing to oppose their path,

diverge again and fall in a diffused beam on the side of the tube.

102. Secondary Radiation.—There are several ways in which this may be shown, but perhaps the easiest is to employ the photographic method. A plate should be placed in a box, the film being *downwards*, and various flat metallic objects, such as gold, silver, and copper coins, or pieces of platinum and aluminium placed *beneath* it with a piece of thin paper inserted between the objects and the film. The closed box is then placed under the tube and a suitable exposure given. The actual duration of exposure will, of course, vary with the intensity of the radiation, the distance of the tube, and the speed of the plate, and must be found by experiment. Development will show distinct images of the objects placed beneath the plate, proving that they have emitted secondary radiation, the effect of which has caused additional action on those portions of the plate immediately above them.

It is evident that the whole area of the film has received the same amount of primary radiation, and that any effect over the objects must be due to the secondary radiation they emit. A careful examination of the images will show that, generally speaking, the denser the metal the more intense the secondary radiation set up, and it will also be observed that the radiation comes from some depth as well as from the surface for, up to a certain distance, the thickness of the metal has a distinct effect. This last fact, namely, that the emission of secondary radiation is not confined to the surface, is proved by using a thin piece of sheet platinum and turning one corner underneath so that it lies away from the film of the plate. The additional thickness of metal will be quite obvious from the intensified action at that place.

103. Ionisation.—The X rays cause an intense ionisation in any gas through which they pass. The ionisation effect can be rendered very striking, as a rapid fall of an electroscope leaf will be observed when the instrument is placed at a considerable distance from the tube, and this can be rendered even more impressive by causing the rays to first pass through considerable thicknesses of various objects.

Experiments demonstrating the absence of any direct reflection or refraction of the rays can also be readily performed, but it should always be remembered that prolonged exposure to the rays is dangerous, and experiments should only be continued for short intervals at a time. If a long spell of work is necessitated by some special experiment or delicate research, ample protection must be provided in the form of metallic or lead-glass screens, etc., or opaque gloves, mask and cloak.

104. Fluorescence produced by Blue and Ultra-violet rays.—As the property of fluorescence is encountered so often in the study of radio-activity, it is of considerable interest to study the fluorescence produced in many substances by the waves of higher frequency in the visible spectrum, and also by ultra-violet rays, and compare the effects with the fluorescence excited by radium rays and X rays. For this purpose it is best to employ a source of radiation which is rich in ultra-violet rays in conjunction with a screen transmitting only the rays of greater refrangibility extending from the blue into the invisible region of the ultra-violet. Such experiments can be made very effective when the arc light is employed in an optical lantern, as it is then possible to use a special screen which transmits practically no visible light, but only the ultra-violet rays. For general experiment, however, it

is only necessary to use a blue glass screen placed in front of a metallic filament electric lamp. A neat lantern may be constructed by placing an "osram" lamp in a small box fitted with a reflector, and inserting a screen composed of two pieces of rather deep blue glass (the size of lantern slides is most useful, 3¼ by 3¼ inches), held together with lantern slide binding strips. An examination of the transmitted light with a spectroscope should reveal only the rays beyond the position occupied by the blue hydrogen line, that is to say, from about the beginning of the blue; but ordinary varieties of blue glass appear to also transmit a narrow band in the region of the extreme red. These extreme red rays, although quite unnecessary, do not interfere with the experiments and may be disregarded.

Among the many substances which fluoresce in blue light, uranium nitrate may be mentioned. This compound is easily procured, and a gram or so should be sealed in a glass tube and held in the rays proceeding from the lantern. The fluorescence of uranium salts, although in no way connected with their radio-activity, is particularly interesting, as it was through the attention which they received from Prof. Becquerel that the radio-activity of uranium was discovered. Objects made of fluorescent uranium glass are especially beautiful in blue or ultra-violet rays.

II

105. Electroscopes.—Many different types of the instrument are now to be obtained, ranging from those of the simplest possible construction to the instrument for delicate research work, fitted with an observing telescope having a micrometer eye-piece. A good electroscope for ordinary experimental work is easily constructed, the exact form being a matter of indifference so long as the insulation is good. The frame of the case may be of wood or metal, rectangular in shape, the back and front being composed of glass; the glass globe pattern is not to be recommended as the shape interferes, to some extent, with the view of the leaf. The best insulating material is, perhaps, sulphur, but paraffin wax is also very good; ebonite is sometimes employed, but unless kept perfectly dry, (a condition not always easy to ensure,) it is apt to allow the charge to leak away rather rapidly.

In the modern form of electroscope, the rod passing through the insulating medium terminates in a metal plate to which the leaf is attached. The plate, being stationary, gives a fixed zero point, and the diminishing angle between it and the leaf during discharge is easily observed and measured.

The leaf may be either gold or aluminium, the latter being often preferred on account of its greater durability, the lightness of the metal rendering a thicker leaf possible without additional weight.

Where accurate observation of the rate of discharge is desired, an electroscope of small dimensions and capacity is most suitable, a very good size for the plate and leaf being about 0·3 cm. wide and 2 cms. long.

The electroscope, backed by a piece of white card, can be set up and viewed with a small telescope having a photographed micrometer scale inserted in the focus of the eye-piece. Another and somewhat simpler method, is to substitute a piece of ground glass, upon which a scale has been neatly drawn, for one of the clear glass sides of the instrument. If now the electroscope be placed in a beam of light coming from a source presenting a small area, (a 4-volt electric lamp will serve,) a sharp shadow of the plate and leaf will be projected upon the ground glass, and will be seen in the same focus as the scale.

For demonstration purposes, a larger electroscope is advisable, for the fall of a longer leaf is more apparent. In this case also, however, the electrical capacity of the instrument should be kept as small as possible, which can be effected by making the plate and leaf very narrow in proportion to their length.

The upper end of the rod usually terminates in a small metallic sphere, but this is not a matter of importance. When showing the discharge due to radium, it is sufficient to merely hold the tube in which it is contained a few inches from the rod, but in the observation of the discharge produced by substances of small activity, or in the accurate quantitative investigation of the radiation emitted, it is necessary to employ an electroscope filled with discharging plates.

A convenient size for the plates is about 5 cms. in diameter, but their exact size and shape can be modified to a considerable extent. The upper one should be

attached to a metallic rod fitted with a screw clamp by which it can be connected to the rod of the electroscope, the lower one being earthed. The rod connecting the upper plate with the electroscope is bent so that the plate is held in a horizontal position at the side of the instrument over, and parallel with, the lower plate. Provision for varying the distance between the surfaces of the plates is made by fitting the lower plate to a stand having

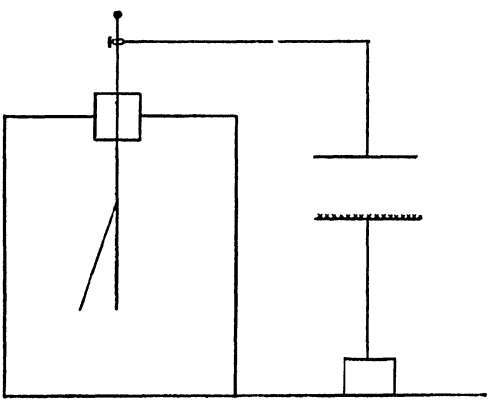

FIG. 11.—Electroscope with Discharging Plates.

a screw clamp which enables it to be fixed at different positions.

Electroscopes for projection with the aid of an optical lantern are especially suitable for demonstration purposes, and are not difficult to construct. A very simple method is to cut a square aperture out of a block of wood of the requisite dimensions, (not less than 3 cms. wide,) and inserting, through sulphur insulation, a piece of copper wire beaten flat at the end in order to form a small plate.

The sides can be formed of glass or mica, but the distance between the internal surfaces should be great enough to prevent the leaf from clinging against them when the instrument is charged. In any case the leaf need not be long, as the magnified image projected on the screen is large enough to render even a comparatively slow discharge visible.

In order to allow the motion of the leaf to be more

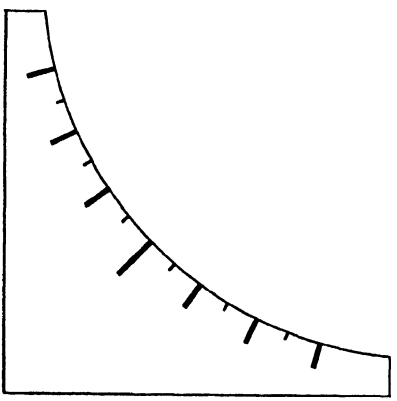

FIG. 12.—Mica Scale for Lantern Electroscope.

easily followed, a scale may be placed inside the instrument, and marked with conspicuous divisions. Such a scale can be made by cutting out a piece of mica in the shape shown in the figure, and sticking very narrow strips of black paper at intervals along the curved edge. Care should be taken that the scale be inserted in the electroscope in such a way as to prevent the leaf from touching it at any point.

The leaf of the electroscope should be as smooth and

even as possible, so that the projected image approximates to a narrow black line; it is also important that the plate and leaf be set quite square in order to prevent a thickened or out-of-focus appearance.

As the image is inverted and it is obviously impossible to overcome this by inverting the electroscope, it is always better to employ an erecting prism when using the lantern for demonstration purposes.

In delicate observations of the rate of discharge by means of a micrometer eye-piece, it is often difficult to obtain a satisfactory image of the leaf for comparison with the scale divisions. The difficulty may be overcome by carefully attaching to the extremity of the leaf a short piece of fine hair. This does not materially add to the weight, and provides a clear and sharply defined object for comparison with the scale lines.

106. Charging.—The operation of charging should always be performed with care, especially with small instruments, as the violent repulsion of the leaf by the plate which occurs with a too heavy charge, often results in injury. For ordinary purposes the sign of the charge does not matter, and an ebonite rod may be employed for charging instruments of moderate capacity.

The method is, of course, that of induction. The electrified rod is gradually brought up to the electroscope terminal until the leaf stands out from the plate at a fairly large angle; connection is then made with earth, (a touch of the finger on the electroscope rod will complete this sufficiently well,) which results in the fall of the leaf which is again repelled from the plate on the removal of the electrified rod.[1]

[1] The process of earth connection is necessary in order to supply a means of escape for the "free electricity" or, in the language of the

The permanent charge thus acquired is of opposite sign to that of the charge inducing it.

With small electroscopes a far more satisfactory way is to gently whip the rod of the instrument with a soft camel-hair brush. This is the better method of charging lantern electroscopes, as the amount of the charge can be regulated with accuracy, and the possible clinging of the leaf to the sides of the instrument is thus avoided.

Electroscopes must, of course, be kept quite dry and, as far as possible, free from dust. For this reason they should be placed under cover in a dry place when not in use, and this also applies to the brushes or rods employed in charging them.

In some cases defective insulation can be traced to the surface of the insulating medium becoming dirty, and it may be found necessary, in the case of sulphur, to scrape it occasionally.

electron theory, for the ingress or egress of electrons as the case may be. The earth connection must, of course, be broken before the removal of the electrified rod.

III

107. Experiments with the Radio-active Elements.—In the manipulation of all compounds of the radio-active elements, the most exact care and cleanliness are necessary, especially in dealing with specimens of high activity. It should always be remembered that the smallest trace of active material may completely interfere with the accuracy of electroscope readings, and, for this reason, the hands should be carefully preserved from any chance of contamination. With highly active preparations of radium, careful handling is at all times additionally important, as excessive exposure to the rays is a source of real danger, but whatever the nature of the active substance, in the science of radio-activity, as well as in all other branches of scientific work, absolute cleanliness and precision should be cultivated on principle.

Although radium compounds are still very costly, a number of exceedingly interesting experiments are possible with only small quantities of the impure salts which contain a large excess of barium, and a few milligrams of such preparations suffice to demonstrate some of the most striking properties of the element. A description of some of the simpler experiments which can be performed with the radio-active elements is given in the following pages, and it is hoped that this may prove of interest.

108. Photographic Action of Uranium, Thorium, and Radio-active Minerals.—A repetition of the experiments originally made by Prof. Becquerel has both an

intrinsic and historical interest. In taking radiographs with radio-active substances, any reliable make of plate may be employed, a plate which is rather rapid being preferable, especially with substances of feeble activity. Care should be taken in the process of development, which must not be hurried. When it is desired to test the activity by the β and γ radiation only, the plate should be inserted in a black paper envelope, the active substance being placed outside. In this way very good radiographs may be obtained by the β and γ radiation from uranium compounds, but as it is necessary, both for the intensity of the action and also for even fair sharpness of definition, that the uranium should be close to the film of the plate, only flat objects can be radiographed. The nitrate of uranium is, perhaps, the easiest to procure, but this salt is not very satisfactory to use on account of its being rather deliquescent, and although the nature of the compound is not a matter of much importance as regards its radio-activity, for convenience the black oxide is to be preferred. It is best to place a few grams of the uranium compound in a small cardboard box and lay this on the plate, inserting any object of suitable dimensions between the box and the envelope. Coins, pieces of wire bent into spiral coils, or flat keys, etc., will yield fairly sharp images, but objects of greater thickness cannot be employed on account of the fact that a diffused radiation proceeds from a large area and makes good definition impossible.

An exposure of several days is usually necessary, but the duration will vary with the quantity of the active material and the nature of the plate used. With a rapid plate, a faint action is obtained in a few hours, but for a well-marked impression an exposure of a week is not too long. A sufficient quantity of the uranium compound

should be employed to make a layer about one-eighth of an inch deep over the required area.

The photographic action produced by the β and γ radiation of thorium is very slight owing to the feeble intensity of the rays, and an even longer exposure is desirable in order to obtain a marked effect. An ordinary

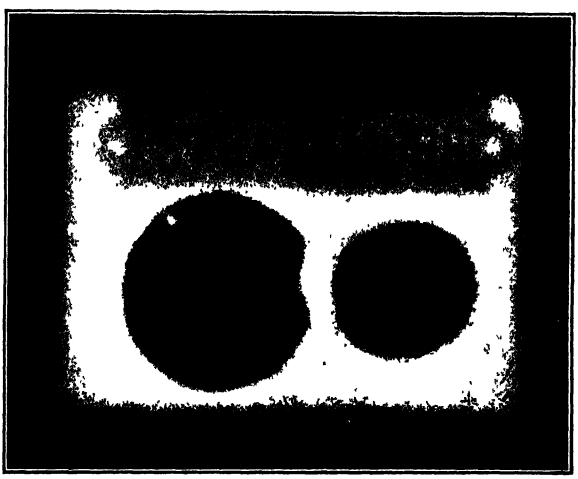

FIG. 13.—Radiograph of antique silver and bronze coins and a piece of sheet aluminium, taken by uranium nitrate (β and γ rays). Exposed about 6 days.

incandescent gas mantle is composed largely of thorium oxide, and a quantity of this compound is thus readily obtainable.

Among the radio-active minerals, pitchblende and thorionite may be mentioned, the latter being usually met with in the form of cubic crystals.

In order to obtain the photographic effect of the α

rays it is necessary to leave the film of the plate uncovered, as the insertion of even a thin piece of paper between it and the active substance is sufficient to stop all action. The active material must therefore be either laid directly on the plate, or supported close above it so that the α particles have only a short distance to travel

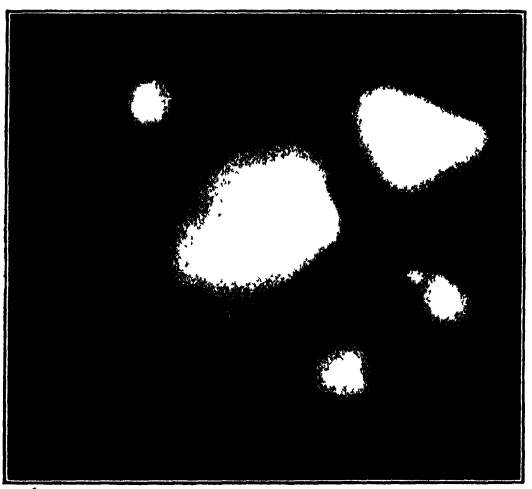

FIG. 14.—Action of pitchblende on a photographic plate (β and γ rays).

in air. Although a certain small reduction of the action results from the intervening atmosphere, the latter method is preferable, as the possibility of any unsuspected chemical action on the film is to a large extent avoided.

The β and γ radiation is, of course, present also; but it is of interest to compare the result of similar exposures with and without the α rays.

Owing to the power of penetration of the β and γ radiation, it will be evident that the mass of the substance employed will determine the intensity of the action; but the case is quite different with the α rays, for, so far as this form of radiation is concerned, it is only the active material at or very near the exposed surface which can be effective, while the volume of the

FIG. 15.—Photographic action of crystals of the mineral thorionite (β and γ rays). Exposed 7 days.

substance is without action owing to the absorption of the α rays within its mass.

Advantage may be taken of this fact to eliminate, to a very large extent, the β and γ radiation while leaving the α rays quite unaffected, by depositing the active substance in a thin film over any required area.

For experiments on the photographic action of the α rays and, indeed, for experiments in general with this

type of radiation, it is convenient to construct radio-active screens by covering a piece of glass or smooth wood with any suitable adhesive, and coating the surface with the active substance.[1] The screen should then be placed in a wooden frame of such thickness as to hold the active surface about one-eighth or one-quarter of an inch above the film of the plate when inverted over it. Such a screen gives very little β and γ radiation, and is convenient for experiments with the α rays.

Experiments on the variation of the action due to the absorption effected by the interposition of thin sections of various solids, or under different conditions of atmospheric pressure are also possible.

109. Ionisation.—For investigation of the ionisation produced by the radiation from compounds of uranium and thorium or from active minerals, an electroscope with discharging plates should be employed. A layer of the active substance should be spread evenly over a metallic disc of the same size as the lower plate, on which it is then placed. After having adjusted the distance between the plates (about 4 or 5 centimetres is usual) the active surface may be covered with a piece of mica or card to cut off the α radiation while the electroscope is being charged.

On removing the mica, the α rays pass through the air between the discharged plates, and the ionisation caused is shown by the rate of fall of the electroscope leaf.

The ionisation due to the β and γ radiation is exceedingly feeble, and a delicate electroscope must be employed in its detection and measurement. In this case the α rays

[1] An effective screen may be made in this way with crushed pitchblende.

must be cut off by the interposition of a sheet of mica. Owing to the fact that the β and γ rays do not suffer very much absorption in the substance of the active compound, a larger quantity can be advantageously employed. With a sufficiently delicate means of detection, the reduction of the ionisation after the radiation has passed through different media can be studied.

110. Fluorescent Action and the Production of Scintillations.—The nature of the fluorescence produced by the α rays has already been described, and the production of the beautiful scintillations by the impact of the α particles on crystalline zinc sulphide was shown to supply a very delicate means of detecting the emission of this form of radiation. By using the transparent screens originally introduced by Mr. F. Harrison Glew, the scintillations produced by the α radiation from uranium and thorium compounds, as well as from all radio-active minerals, are readily visible.

The active substance is spread in a thin layer on glass (an area of rather less than a square inch is all that is necessary), and the fluorescent screen placed over it, the two surfaces being kept from actual contact by the insertion of a strip of card at the edges of the screen. The scintillations due to the impact of the α particles on the crystals of the sensitive screen are clearly visible when the latter is viewed in a darkened room with a lens having a focus of about 1·5 to 2 centimetres. As the hand is generally somewhat unsteady, it is better to use a lens fixed in a short brass tube, and fitted with screw adjustment for focussing, as this can then be placed on the screen.

Observations of this kind are preferably made at night, for the eyes are then naturally most sensitive; if made

during the day it becomes necessary to wait several minutes in the dark-room before anything is perceptible.

111. Testing Minerals.—Although not suited for accurate quantitative work like the electrical method, the fluorescopic means of detecting the emission of α rays is often both convenient and quick, and mineral specimens are readily tested in this way. The specimen to be tested may either be ground down to a smooth surface, or a small piece of it reduced to a coarse powder. In the former case the screen must be placed against the prepared surface, and just kept from actual contact by strips of thin card gummed along its edges; and in the latter the crushed mineral should be inserted in a shallow cell cut in vulcanite or other suitable substance, the screen being laid over the aperture.

The room in which the observations are made should not be absolutely dark, as diffused light of very feeble intensity will be found rather helpful. The surface of the screen should be just faintly visible through the lens, and this condition is very well fulfilled by the observer having a dim light some little distance behind him.

Great care is necessary that screens used in testing do not become radio-active through contact with the radio-elements or active emanations. An exceedingly feeble acquired activity will completely spoil a screen for purposes of testing, and a special box should be provided in which all testing screens must be kept when not in use. Even with these precautions it is always advisable to first test the screen itself before using it for testing minerals, and this may be done by placing it on a carefully cleaned piece of glass which has never been exposed to possible contamination, and noting if any scintillations are visible under these conditions. Only a very few should be seen

within a minute or so if the screen is in good condition. It seems almost impossible to get a screen which will show absolutely no action in the space of a few minutes, and it appears that ordinary forms of matter may be radioactive to an extent sufficient to explain this slight action. Another explanation is possible, however, on the assumptions that the crystals may suffer occasional fractures by conditions of temperature or other unexplained physical causes, which would result in the production of scintillations closely resembling those produced by the impact of α particles. If such fractures really occur, it is certain that they account for only a very insignificant proportion of the total number of scintillations observed, even with substances of small activity like thorium, and may be disregarded except where the observed action is so extremely feeble as to render its cause doubtful. In such cases the more accurate and refined electrical method must be employed to settle the question.

A fluorescent screen also supplies a convenient means of observing the penetration of the α particles, by inserting pieces of thin metallic foil between the active surface and the screen.

It is, of course, essential that the zinc sulphide, from which the screens are made, is kept from all sources of possible contamination.

As regards the actual appearance of the scintillations themselves, the effect varies, not only with the magnifying power employed, but also with the size of the crystalline fragments, and the quality of the salt, this latter factor being very important, as some varieties are not nearly so good for showing the scintillating effect as others. In addition to this, however, the velocities of the α particles appear to be responsible for a variation in the brightness

of the scintillations. Using the same screen under the same conditions, a very perceptible difference in brightness can be at once detected between the scintillations produced by the α particles emitted by actinium, and those emitted by uranium, the former being distinctly brighter.

112. Thorium Emanation.—Although the volume of the emanation evolved by thorium is inconceivably minute, this is to a certain extent compensated for by its intrinsically intense radio-activity, and some very interesting experiments can be performed by using a fairly large quantity of thorium, although even then the effects observed are always small and require careful observation.

In the removal of the emanation from a thorium compound, it is convenient to use a salt which is soluble in water, and for this purpose the nitrate is well adapted. On dissolving thorium nitrate in water, the emanation is liberated and may be removed by passing a stream of air through the solution. A certain amount of the gaseous emanation passes away at the surface of the liquid without the necessity of being carried away by an air current.

If a small quantity of the nitrate be dissolved in a test-tube and a testing screen placed across the mouth, scintillations due to the α particles emitted from the disintegrating emanation atoms will be visible in the dark, and, although these are very few, the action is perfectly definite.

It is clear that a better effect would be produced by collecting as much of the emanation as possible from a given quantity of thorium into a comparatively small space. For this purpose the apparatus shown in the illustration may be employed. A long narrow cylinder of glass is fitted with a thin cork having a hole in the middle about 2 cms. in diameter. Over this aperture a

testing screen is fitted with some adhesive medium, care being taken to render it air-tight. At one side of this a narrow tube enters through the cork and is continued downwards to the bottom of the cylinder, forming an inlet from the air stream. The outlet is provided by a similar tube, but this is only inserted as far as the lower surface of the cork, the outer end being bent downwards and terminating in a point with a small aperture. The glass cylinder may be about 3 cms. internal diameter, but the actual dimensions do not greatly matter. The cylinder should be filled to within a short distance from the top with a solution of thorium nitrate, (about an ounce will serve,) and the cork inserted and rendered air-tight by being waxed round the edge.

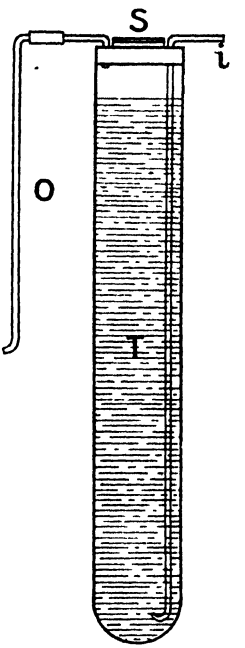

FIG. 16.—Apparatus for observing scintillations produced by the α rays emitted by thorium emanation.

T = thorium solution; i = inlet tube for air; O = outlet tube; S = fluorescent screen.

On passing a slow current of air through the inlet tube, the emanation is carried upwards to the screen, where its presence is at once detected by the scintillations observed, after which it is carried away through the outlet tube, and can be used for other experimental purposes. Owing to the very short period of thorium emanation, it can only be investigated for a little while

after its removal from the thorium solution. As its decay, however, is balanced by its evolution in the thorium solution, a practically continuous supply can be obtained.

It is better to employ a continuous and uniform air current, but a rubber bulb and valve (similar to those used for scent sprays) will serve as long as the air stream is gentle. This condition can be obtained by drawing off the bottom of the inlet tube to a small aperture.

The disintegration products of uranium and thorium exist in quantities infinitesimally small, and for accurate investigation of their activity delicate instruments are necessary. The isolation of Th. X by precipitating the thorium from solution by ammonia is an interesting experiment, however, as the residual activity due to this product is considerable.

IV

113. Experiments with Radium.—The residue remaining after the extraction of the uranium from pitchblende can be used for experiments on the photographic and ionisation

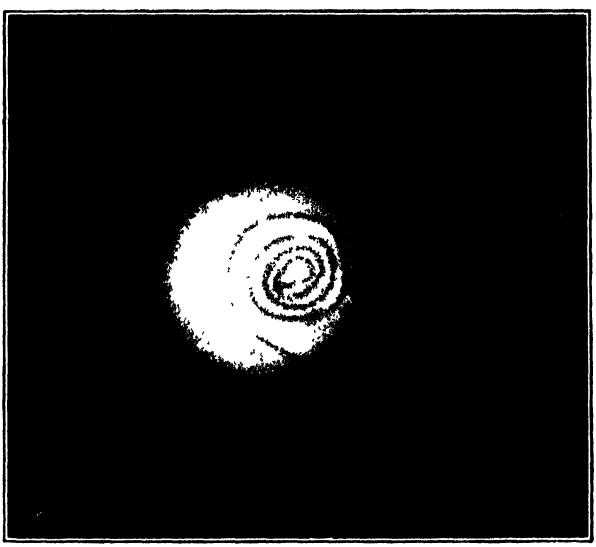

FIG. 17.—Radiograph of wire spiral by pitchblende residue (β and γ rays). Exposed 7 days.

effects of the rays in a similar way to that described for compounds of uranium, etc., the action being chiefly due to the exceedingly minute quantity of radium contained

within it. The composition of the residue is probably subject to variation, but it usually appears as a greyish mauve powder having an activity not much greater than that of pitchblende.

Preparations of radium having a comparatively high activity should always be sealed in glass tubes, or in the specially constructed ebonite cells which can be obtained for the purpose. The cell is cut in the centre of the upper surface of a small circular block of ebonite which is made slightly convex, the aperture being closed with a mica cover held tightly in position by a brass flange screwed down over the ebonite. In enclosing a radium compound in such a cell, it is necessary to make sure that the mica is perfectly sound and not too thin, and care should be taken to avoid risk of its being accidentally cracked or cut when the cell is in use.

The enclosure of radium in either a glass tube or a cell completely stops all the α radiation, but the β and γ rays suffer very little absorption. The use of a cell is generally much more convenient than a glass tube, and the risk of breakage is avoided.

114. The α rays.—In experiments with the α rays, it is clear that a comparatively large quantity of the active material is neither necessary nor desirable on account of the fact already mentioned, that the rays suffer complete absorption within the mass of the radiating substance, while the effects of the β and γ radiation are correspondingly increased. The form in which the active compound should be used is a thin layer and, when a copious α radiation is desired, the actual activity of the radium salt must be taken into consideration, and not merely the quantity of it which is available.

On account of the great power of ionisation possessed

by the α rays, a very impure radium salt will suffice to produce a rapid discharge of an electroscope. For showing this discharging action, a salt having an activity of about 1000 units will be found very suitable, and an active surface may be prepared by depositing a thin film of crystals from a solution of the salt on a circular glass or metal plate about 2 cms. in diameter. This serves well as a temporary screen for experiment, but it is unsatisfactory for permanent use on account of the liability of the crystals to become detached from the surface on which they are deposited and the risk of being accidentally rubbed off by contact.

A permanent screen for the purposes of demonstration can be made by covering a disc of celluloid with a solution of a radium salt in amyl acetate which dissolves the surface of the celluloid and, on evaporation, leaves it impregnated with the radium compound.

Such a screen may be lightly rubbed or even washed without removing the activity and, although there is a slight absorption of the radiation owing to the fact that the α particles have to traverse an extremely thin film of celluloid, this is more than compensated for by its convenience. For general experiment the screen may be fixed at the bottom of a shallow cylinder fitted with a screw cap.

The ionisation caused by the α radiation is very well demonstrated by simply holding the active screen a few centimetres from the electroscope, but the rapid leak of the charge may be shown to cease abruptly on placing a piece of mica or card in front of the active surface, thus proving the easy absorption of the α rays by matter.

115. Ionisation Range.—On account of the removal of the emanation and successive products by solution, a newly

made screen does not at once attain to its full activity, nor are the α particles emitted characterised by the ionisation range exhibited in the case of those of the product Ra. C. As the power of causing fluorescence appears to cease at about the same point as the ionisation limit, an interesting experiment may be made by fixing a transparent zinc sulphide screen horizontally by the side of a divided scale, (a centimetre rule will serve,) and placing a radio-active screen on a movable stage fitted below it. When the screen is viewed with a lens, the characteristic scintillations will be observed when the active surface is close beneath it. On increasing the thickness of air through which the rays have to pass by lowering the stage, it will be noticed that the scintillations become fewer in number. This is partly owing to the fact that the α particles are projected in all directions and that therefore a smaller number can fall on any given area of the screen, and partly on account of the reduction of the kinetic energy to below the critical value in the case of the α particles having the smallest ionisation range. Up to about 3 cms. the first cause, namely the spreading out of the rays, will be almost wholly responsible for the smaller number of scintillations observed but beyond this, atmospheric absorption reduces the rays from the various products in order of their ionisation ranges.

This experiment is only an approximate indication, however, on account of the several other factors which determine the production of scintillations in a fluorescent screen, and too much importance must not be attached to it when considered from the point of view of quantitative work. Fluorescent compounds, as already explained, vary very much in their degrees of sensitiveness, and it will also be noticed that the scintillations become individually

fainter as the distance between the active surface and the screen becomes greater.

The celluloid screen described above is not suitable for this experiment as it is important that the α particles enter the air with unimpeded velocity, and in order to fulfil this condition a very thin film of a highly active radium salt should be deposited on glass.

The above arrangement of fluorescent and radio-active screens will also be found useful in experiments on the penetration of the α rays through various substances in extremely thin sheets.

That the α particles travel freely through a vacuum can be shown by placing a fluorescent screen within a glass tube, and a metallic plate rendered active by a deposit of radium at the other end of it. As the air is gradually exhausted by connecting the tube with a mercury pump, the ionisation range of the α particles grows longer until they finally reach the screen with sufficient velocity to cause fluorescence. By coating the interior of the tube with zinc sulphide, the gradually increasing range of the α rays may be followed; it is, however, important to ensure that the scintillations observed are not caused by the diffusion of radium emanation in the tube.

116. Fluorescence.—The fluorescence of zinc sulphide and the production of scintillations has already been sufficiently described in connection with the spinthariscope; a variation of the instrument can be made, however, by treating the screen itself with a weak solution of a radium salt and covering it with mica. In some respects the effect is, perhaps, more beautiful, but the use of a needle in the usual way conveys the idea of the radiation proceeding from the radium deposited on it, and in this

respect gives a more accurate presentation of the real action.

For the study of the action of α radiation of fluorescent substances in general, a screen should be prepared with a radium salt of high activity; nearly pure if possible. It is only necessary to use a very small quantity of radium as, in addition to the thinness of the deposited film, the diameter of the screen need not be more than 1 cm. or so.

The substance to be experimented with should be preferably coated on glass, as the radium can then be placed beneath it, but it is often only necessary to expose it to the action of the rays in the usual way. When close to the radium, zinc sulphide, willemite, etc., glow a very beautiful green, the action being too intense to be resolved into separate scintillations by the use of a lens. With a much less copious α radiation, the behaviour of different specimens of diamond with respect to the production of scintillations may be observed.

117. Duration of a Scintillation.—The experiment demonstrating the extremely brief duration of a scintillation by means of a moving screen can be performed in various ways. It is a good plan to have the scintillations produced on a stationary screen in the field of view of the observing lens at the same time, but this is rather difficult to arrange in a satisfactory way. A method which gives practically the same conditions of observation is to attach a disc of ebonite or wood to the axle of a small electric motor which can be worked in a vertical position, and to fix a circular fluorescent screen (about 2 cms. in diameter) in the centre of it. The screen should be rendered radio-active by a very weak solution of a radium salt, the amount deposited on the crystals being only sufficient to show the scintillations well separated from

one another. An observing lens having been arranged in position over the centre of the screen, and the latter properly focussed so that the flashes appear as points of light on a dark background, the motor should be started. A resistance in circuit can be made to control the speed of revolution, which should be at first moderately slow. It is clear that any scintillations occurring at or very near the centre of the field of view will be practically stationary, while those seen at other parts of the field will have velocities depending on their distances from the centre. The speed of revolution should now be increased, the central scintillations being used as a means of comparison, and it will be noticed that, unless the screen is rotating with very considerable velocity, there is nothing in the appearance of the flashes to denote rotation, the marginal scintillations still seeming fairly sharp. A perceptible lengthening out of the flashes into streaks of light can be produced, however, by increasing the speed of the motor beyond a certain point, and if this speed be known, an estimate of the duration of the flash can be made. It is important that the motor works smoothly, and that the disc and screen are accurately set in position in order to ensure that there shall be no simultaneous vibratory motion.

118. Photographic Effect.—The photographic action of the α rays may be tested at various distances from the plate by using a film of radium on glass or celluloid as already described, one half of the exposed area being covered with mica to give a means of comparison between the part exposed to the whole radiation and that from which the α rays were cut off, and which was therefore only acted upon by the feeble β and γ radiation necessarily present also.

In any experiments where the action of α radiation is desired without simultaneous β or γ rays, polonium (Ra. G) should be employed. Metal discs can sometimes be obtained with an invisible film of polonium deposited electrolytically upon them, and these should be used if possible, as specimens of impure compounds containing polonium will probably be found to emit a certain amount of β and γ radiation owing to some other radio-active body being present in them.

119. β and γ radiation.—In order to demonstrate the properties of the β and γ rays of radium effectively, about 2 or 3 milligrams of a practically pure salt should be used, but for purposes of experiment much less than this will serve. The writer has found 50 mgs. of a barium salt containing 1 per cent. of radium sufficient for many experiments with the rays for, in the majority of cases, the magnitude of the effects is of secondary importance so long as the results aimed at are obtained. When not employed in the process of experiment, radium should always be kept in an outer case of thick metal, (preferably lead,) in order to avoid the chance of spoiling photographic plates or films which may be accidentally left near it; the radiation, even at the distance of some yards, is also quite sufficient to interfere with experiments necessitating the use of an electroscope by reason of the ionisation of the air in the room.

120. Ionisation.—Although all α radiation is cut off by enclosing radium in tubes, etc., the ionisation due to the β and γ rays is very considerable on account of the fact that the whole mass of the radium is effective in producing it, and some striking experiments are therefore possible with a few milligrams.

A rapid fall of the leaf takes place when the radium is held several feet away, and the penetration of the rays is made evident by causing them to pass through pieces of wood and thin metal, etc. With a sensitive electroscope provided with a scale, quantitative experiments on the absorption effected are possible, and the effect of the γ rays alone is perceptible after the β rays have been filtered out by 1 cm. or so of lead. With smaller quantities, the distance from the electroscope must be reduced to a few inches to produce a rapid discharge, and it will be noticed that the best effect is produced when the radium is held at a certain distance which will vary with the activity of the specimen and the capacity of the electroscope. This distance depends on the rate of the removal of the ions produced in the air under the influence of the electrostatic field around the terminal of the charged electroscope, and the saturation current is obtained when the ions are removed as fast as they are produced. As this will occur under any given conditions when the ionising agent is at a certain distance, a nearer approach is not followed by a corresponding increase in the rate of discharge.

121. Photographic Action.—The photographic action of a few milligrams of radium will be found very intense and, owing to the fact that the radiation proceeds from a small area, radiographs of such objects as keys in a purse or wooden box, etc., yield fairly sharp images when the radium is placed some inches above them. With impure salts under the same conditions similar results are obtainable by increased exposure. The penetration of the rays through various thicknesses of metal offers an interesting field for experiment, and so also does the subject of secondary radiation.

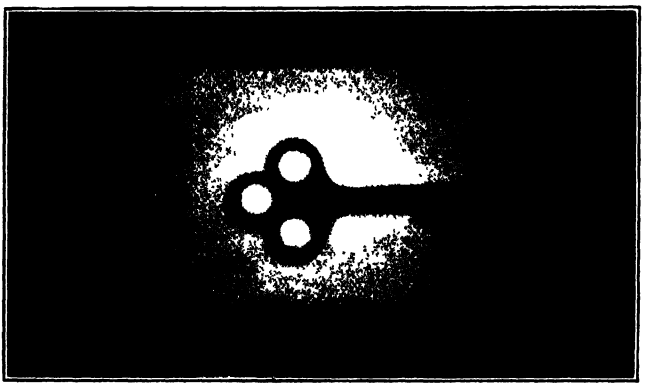

FIG. 18.—Radiograph of key taken with (about) 200 mgs. of 0·1 per cent. radium-barium-bromide in glass tube.

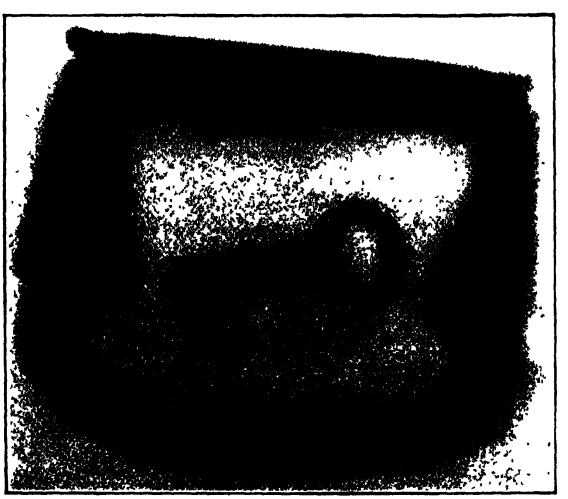

FIG. 19.—Radiograph of key in purse by 50 mgs. of 1 per cent. radium-barium-bromide in cell. Exposed 26 hours.

The reversal of the image by prolonged exposure is possible, and an example of the action is here produced.

With a suitable electro-magnet, a repetition of the experiments of Prof. Becquerel on the deviation of the β rays may be attempted, but it must be remembered that, as radium emits its rays equally in all directions, it

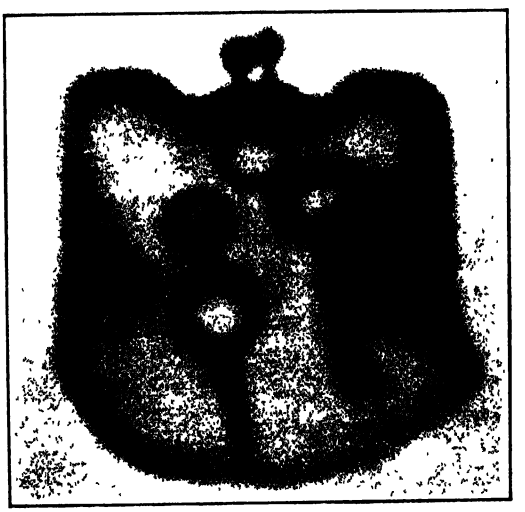

FIG. 20.—Radiograph of keys in purse by 50 mgs. of 1 per cent. radium-barium-bromide in cell

is necessary to first obtain a narrow beam by passing the rays through an aperture in a lead block.

122. Fluorescent Action.—With a few milligrams of nearly pure radium, it is also possible to show such objects as keys, coins, etc. in a purse by means of a fluorescent X-ray screen, (barium-platino-cyanide,) and a bright spot of light is visible after the rays have passed through a penny

piece; indeed, the action of even so small a quantity as 50 mgs. of a 1 per cent. salt is still quite perceptible under these conditions. With careful observation with a lens, a very interesting phenomenon may be noticed in connection with this fluorescence. If a small quantity of radium, (about

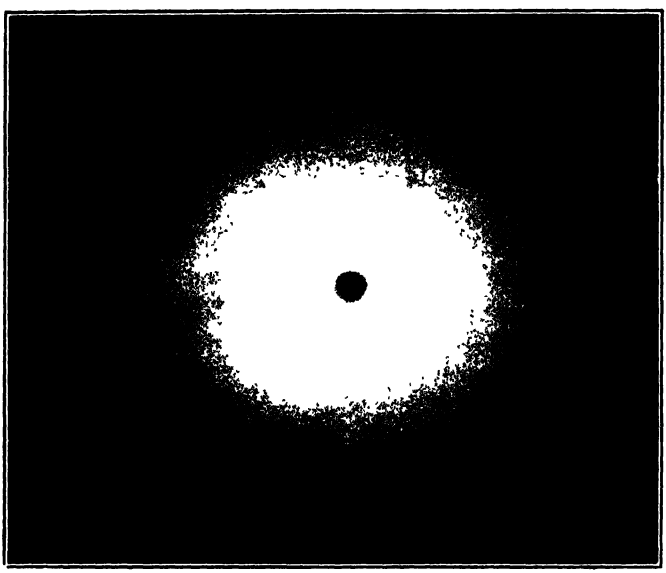

FIG. 21.—Reversal produced by radium rays.

20 mgs. of a 1 per cent. salt,) in a cell be brought up behind a barium-platino-cyanide screen, a not very bright spot of fluorescence will be seen, and observation with a short focus lens will probably not reveal anything but a steady glow, but on reducing the radiation by the interposition of a coin, (a shilling piece will do,) the feeble

fluorescence which is still visible will be seen to present a flickering appearance. This unsteadiness is not very marked and, in order to see it well, the radiation must be reduced to a certain intensity without the necessity of using such a thickness of metal as will absorb all the β radiation, hence it is necessary to use only a small quantity of impure radium. The appearance of the screen gives the impression of faint, nebulous scintillations superimposed on a feeble steady glow, and the most probable explanation seems to be that the electrons forming the β rays are responsible for the action, while the steady glow is attributable to the γ radiation. If this explanation is correct, the action is exactly analogous to the α ray scintillations of the spinthariscope.

Crystals of barium-platino-cyanide are very sensitive in their power of fluorescence under the influence of β and γ radiation, and the fact that they are translucent enables the light to be perceived throughout a considerable thickness of the salt, so that a much larger amount of the incident radiant energy is transformed into visible fluorescence. For these reasons it is possible to construct an extremely sensitive detector for feeble γ radiation by placing some crystals in a small cell to a depth of about 5 mm.

The cell may be made by cutting a circular aperture through a small piece of wood of the requisite thickness, the sides being closed by thin sheets of mica. The use of a lens to view the crystals enables the much fainter fluorescence to be detected than would be possible if viewed with the unaided eye alone, and in this way the γ radiation from a small quantity of radium can be detected after passing through a very considerable thickness of metal.

123. Colouration of Glass.—After radium salts have been sealed in glass tubes for some time, a distinct colouration of glass is noticeable. The time required to produce this, of course varies with the activity of the specimen and the composition of the glass. Even a decigram of a compound of only 240 units activity will produce a faint violet tint after several months, while a decided colour is produced under the same conditions by a compound of 1800 units activity. With highly active specimens the action is much more rapid, but the discolouration is brown or greyish. By inverting a cell containing about 10 mgs. of pure radium bromide on a piece of plate glass, a discoloured spot very soon appears, which gradually extends deeper into the glass until it finally penetrates to the other surface and expands laterally. The extension of this colouration can be well observed at different stages by viewing it through the end of the glass which, for this purpose, should measure about 1 in. square.

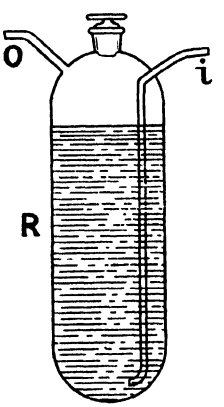

FIG. 22.—Tube for the removal of radium emanation from solution.

R = radium salt in solution; i = inlet tube for air stream; O = outlet tube for air.

124. Radium Emanation.—In order to obtain the emanation from solution, a small cylindrical glass vessel similar to that shown in the diagram should be used, the inlet and outlet tubes both being fitted with small stop-cocks. The apparatus should be small in order to avoid using a comparatively large quantity of water, or carrying off the emanation mixed with an unnecessarily

large volume of air. The inflow of air must be very gentle and this may be regulated, to a large extent, by the proper adjustment of the stop-cock.

The experiments which may be performed with the emanation will naturally be dependent, to some extent, on the quantity of radium in solution, but the actual purity of the salt is a matter of indifference so long as the quantity of solution is not unduly large. An exceedingly small quantity of radium will yield sufficient emanation to cause densely crowded scintillations on a zinc sulphide screen, owing to the α radiation emitted. If a short piece of rubber tubing be connected to the outlet tube and carried into a small aperture cut in a wood block covered with a screen, (sealed down over it to prevent the escape of the emanation round the edges,) the emanation will diffuse into it, and reveal its presence by the scintillations set up when the stop-cock is opened.

With larger quantities of the emanation, the α ray action becomes intense, and is marked by bright fluorescence which is well shown by connecting the outlet tube with a narrow glass tube filled with zinc sulphide or willemite fragments, the emanation being carried through it by a gentle current of air. A somewhat simpler method, and one which confines the emanation within the tube, is to coat the inner surface of a small test-tube with the fluorescent substance, and connect it with a vessel containing a radium solution by a narrow glass tube fitted with a stop-cock. No light is observed until the tap is turned, after which the emanation gradually passes into the upper tube by the process of diffusion, its presence being evident by the whole of the coated surface becoming brightly luminous.

When it is desired to remove the emanation entirely,

the apparatus previously described should be used, as the emanation can then be isolated, (mixed, of course, with air,) and its gradual decay in the process of transformation into the solid active products of the radium series separately investigated. For instance, the gradual production of Ra. C in a glass tube into which the emanation had been introduced, should be capable of detection by the photographic method owing to the emission of the β and γ radiation characteristic of this product. The so-called "induced activity" of objects with which the emanation has been in contact, and the consequent formation of the active products, can be observed in a qualitative manner either photographically or with the aid of an electroscope.

FIG. 23.—Method of showing fluorescence due to the α radiation from radium emanation.

A = tube coated internally with fluorescent zinc sulphide; B = radium in solution; S = stop-cock.

Having removed all the emanation which is available at any one time from a given quantity of radium, it is necessary to allow the solution to stand about a month in order that the emanation, which is, of course, being continually evolved, may have time to reach, approximately, its equilibrium volume.

Owing to the attraction exerted by a negatively charged body on the positively charged emanation atoms, a high activity may be conferred on a wire by introducing it into a tube containing the emanation and maintaining it at a negative potential for some time to allow of the deposition of the emanation over its surface.

In experiments with radium emanation, it is often

very undesirable to allow it to escape into the air of the room after passing through the various tubes, etc., used, for although it rapidly diffuses, it is possible that a sufficient quantity might come in contact with an electroscope to introduce a slightly increased rate of discharge by reason of the activity acquired. In most cases, especially in experiments with small quantities of radium, it is necessary to keep the emanation confined to the apparatus in order to get the maximum effects; but whenever a stream of air, passing through the apparatus and carrying the emanation with it, is desirable, its escape into the surrounding air may be prevented by receiving the air stream under water in a small inverted vessel in a similar manner to that employed in receiving gas from a retort.

The emission of α rays by the radium in solution after the removal of the emanation, can be shown in a very beautiful way by dropping a small quantity of zinc sulphide into the solution. This compound, being insoluble in water, sinks to the bottom, and glows brightly under the action of the α particles emitted by the radium. There can be no doubt that the range of the α particles in water must be very restricted, but as the solution is in actual contact with the fluorescent crystals on all sides, their action is still very marked.

For obvious reasons it is not permissible to bring radium emanation into direct contact with an electroscope, but the discharge due to the ionisation of any gas with which it is mixed, by reason of the α rays emitted, can be shown by passing it into a chamber containing an earthed wire, and another well-insulated wire a short distance from it which is connected with the electroscope.

125. Actinium.—Experiments on the ionisation and

photographic effects of actinium rays can be made in a precisely similar way to the methods employed with radium, and this element calls for no special comment in this connection except that the α rays it emits produce very beautiful scintillations on a zinc-sulphide screen. The flashes certainly seem somewhat brighter than those produced by the other radio-active elements, and this would seem to indicate that the α particles are emitted from actinium itself[1] or one of its products with an unusually high velocity.

The preparations of actinium generally obtainable are not possessed of a very high activity, but as the element itself has apparently never been obtained in a pure form, its true activity is unknown.

The extremely brief period of the emanation renders the observation of any effects due to it a matter of considerable difficulty.

[1] Reference to the list of actinium products will show that it is at present unknown whether actinium itself emits any rays. The α particles responsible for the above-mentioned effect must presumably be due to radio-actinium, Act. X, or the emanation.

V

126. Experiment with Floating Magnetic Needles.—The experiment of illustrating, by means of floating magnetic needles, the electron systems which hypothetically constitute atoms, is a very fascinating one, as the different formations are strongly suggestive of the periodically recurring similarity of properties displayed by the various chemical elements.

The pieces of cork through which the needles are passed should be uniform in shape and size, and as small as will suffice to properly support the needles. A cork-borer is the best means of cutting the discs.

The process of magnetising the needles needs care, as it is necessary to obtain them as equal as possible in order to ensure symmetrical figures.

Probably the best method is to insert the needles (a few at a time) between the pole-pieces of a good electro-magnet, maintaining a constant field on each occasion. The current should be stopped before the removal of the needles from between the poles and started again when the next set are in position. The needles themselves must, of course, be capable of retaining their magnetism, and ordinary steel sewing needles may be made to answer very well. The control field, corresponding to the sphere of uniform positive electrification in the atom, can be supplied by either a permanent bar-magnet, or an electro-magnet which may be supported either above or below

the vessel in which the needles are floating. In some respects an electro-magnet is to be preferred, as the intensity of the field can be varied by altering the strength of the current without the necessity of moving the magnet itself.

The needles should be thrust about two-thirds or three-quarters of their length through the cork discs with their like poles all in the same direction, and introduced one by one at the side of the vessel, which should preferably consist of a shallow circular glass dish about a foot in diameter. The magnet having been adjusted under the table on which the dish stands, a little experiment will soon show the best intensity of field for the formation of fairly compact figures. It will be noticed that a certain configuration may be wholly altered by the addition of another needle, illustrating the change from one group to another which follows after a small increase in atomic weight. The needles should not be placed in the centre of a group, but allowed to approach from the side of the vessel in order that the motions of those already in the group may be more carefully observed. A variation in the intensity of the control field is followed by an immediate expansion or contraction of the figure without any alteration of the formation. Twenty needles seems about the maximum number which can conveniently be employed without the risk of forming irregular figures, although a larger number may be found possible if the magnetisation of the needles is very uniform.

127. Lectures and Demonstrations on Radio-Activity.—The interest created by the discovery of the property of spontaneous radio-activity is so general that lectures and demonstrations on the subject are almost always sure to prove popular. Unfortunately many of the most

beautiful and interesting experiments can only be properly appreciated by a comparatively few persons at a time, but with the aid of a lantern, a good deal may be done to hold the interest of a fairly large audience. The importance of numerous diagrams in the form of lantern slides will be evident, as any experiment is at once rendered more

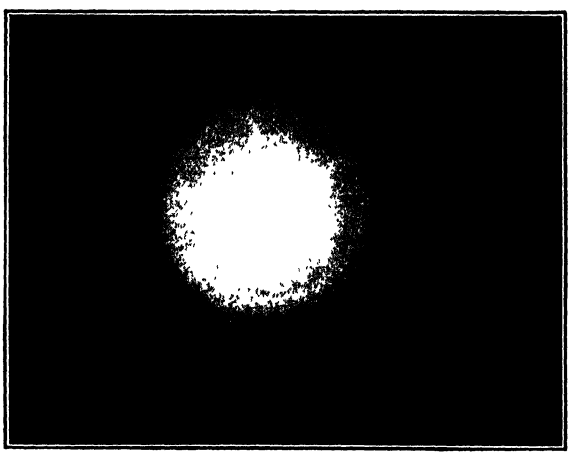

FIG. 24.—Secondary Rays from γ radiation. Auto-photograph of clock wheel after primary radiation had been filtered through sheet lead $\frac{1}{8}$ inch in thickness.

intelligible when the exact conditions are shown. Diagrams executed in indian-ink on smooth white paper are well suited for photographic reproduction as lantern slides, and should be drawn very much larger than required by the limits of the slide in order that any small irregularities may be minimised in the process of reduction, and not appear too conspicuously in the subsequent projection on the screen.

The principle of fluorescence can be illustrated by means of blue or ultra-violet light, and various fluorescent

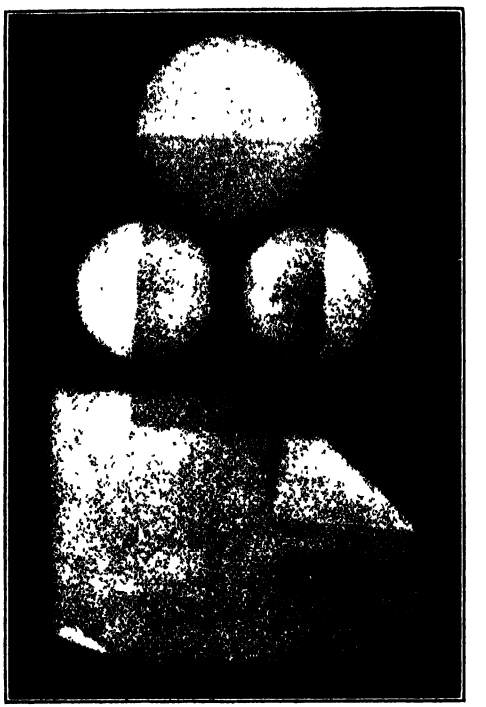

FIG. 25.—Secondary radiation (from radium rays) of gold, silver, and copper coins, and sheet platinum. The penetration of the secondary rays is shown by the increased effect of the radiation where the platinum foil is folded back at two corners.

substances in the manner already mentioned. For the transmission of the ultra-violet rays only, it is necessary to employ a special screen in the slide carrier, and the

arc electric light is also very desirable as it is rich in these rays.

FIG. 26.—Action of a Welsbach gas mantle (which contains thorium) on a photographic plate.

Radiographs by radio-active minerals, uranium, thorium, and especially by radium, are often good enough for reproduction as lantern slides, and the photographic effect

of secondary radiation can also be shown in this way. In some cases the original negative may be projected upon the screen in illustration of some special point or experiment.

The discharge resulting from ionisation due to the α or β and γ rays is best shown by the lantern electroscope, but as the image of the leaf is inverted, the use of an erecting prism is desirable.

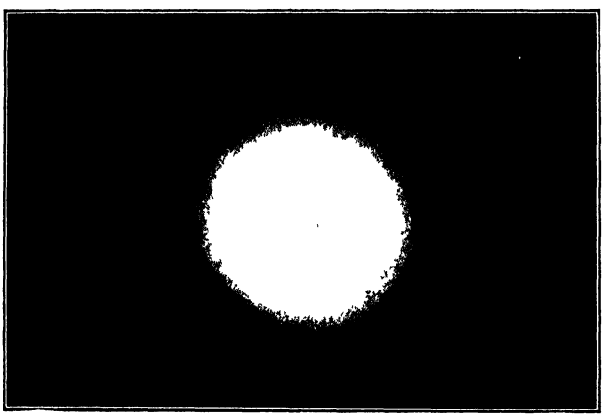

FIG. 27.—Photographic action of 50 mgs. of 1 per cent. radium-barium-bromide through a penny. Exposed 21 hours.

The so-called radium "clocks" can also be projected on the screen, illustrating to a large audience the property possessed by radium of acquiring an electric charge by the stoppage of the positively charged α particles by the glass of the inner tube. Another effective demonstration in connection with this apparatus is the periodical sounding of a small electric bell on each discharge of the leaf against the earth contact. This is rendered possible by

connecting the earth contact of the "clock" to one terminal of the coherer of a small radio-telegraphy receiver, the connections of the instrument being exactly as usual. The small amount of electricity supplied by the charged leaf is sufficient to break down the insulation of the metal filings in the coherer, which thus closes circuit with the relay, causing the bell and decohering apparatus to come into action. In order for the apparatus to work properly, it is necessary that the coherer shall be small and of suitable sensitiveness, and a little experiment in this direction may be required to obtain the requisite conditions. A radium "clock" containing two milligrams of nearly pure radium should discharge in less than a minute if well made. The best pattern is that in which one of the leaves is replaced by a metal plate after the manner of an electroscope; this ensures a quicker and more regular action and will be found in every way preferable.

Lantern slides showing, (in their proper colours,) the principal lines in the spectra of the gases of the argon family, and also of many of the ordinary elements can now be obtained, and those showing the spectra of radium and barium, and also of the emanation, helium, neon, and argon are very interesting in connection with the theoretical conceptions introduced by a study of the subject. With a lantern arranged for the projection of horizontal objects, the floating magnets may be projected on the screen if a clear glass vessel be used, the control magnet being placed under the reflector in front of the condensers.

In addition to the lantern, a certain amount of apparatus will be necessary for demonstration and exhibition. A glass case containing sealed tubes of various radio-active salts illustrative of the gradual purification of radium, and

also specimens of radio-active minerals and ores should be on view. The properties of the kathode rays, including the magnetic deflection of the stream, can be demonstrated by suitable tubes worked by a coil. The invisible character of the rays emitted by the radio-elements can be illustrated by means of an X-ray tube and fluorescent screen, the similarity of the type of radiation being remarked.

With reference to the radiation from radium, the experiments will necessarily depend on the quantity available, but the discharge of an electroscope or electrified silk tassel by means of the α rays can be easily shown with an active screen, (radium on celluloid,) like that already described. The penetration and fluorescent effects of the β and γ rays are best demonstrated by an X-ray screen or a cell containing crystals of barium-platinocyanide.

With a few milligrams, the discharge of an electroscope is possible at a distance of some feet, and this is always an effective experiment. The beautiful scintillations produced by the α rays are well seen with the spinthariscope, and if possible two or three instruments should be provided. A convenient way of setting these up is to fit them into the upper ends of tubes fixed at an angle in firm stands so that they can be placed on a table after the manner of a microscope. This enables the screens to be viewed without the necessity of passing the instruments from hand to hand.

The bright fluorescence produced by the α rays, when the radiation is sufficiently copious, is best shown by treating a quantity of zinc sulphide with a solution of radium, (a salt of 18,000 units activity will be quite sufficient). This method leaves a film of radium deposited round

every crystalline fragment and the effective α radiation is therefore at a maximum, as the radium is "all surface" so to speak. A striking effect is possible with a very small quantity of the active salt, a small glass tube containing about 0·5 gram of zinc sulphide being visible at a distance of several yards after having been treated with a solution of a 1 per cent. salt (say 20 mgs. per c.c. of water). Experiments with radium emanation are generally only adapted for demonstration before a few persons at a time unless a comparatively large quantity of radium is available, and the fact that the experiments cannot be repeated until the radium has had time to evolve fresh emanation, renders them unsuited for large audiences. The discharge due to the ionisation of any air with which the emanation is mixed can, however, be easily shown with a very small quantity of radium in solution, and a screen rendered luminous by the α rays emitted by the emanation can be set up like a spinthariscope. The period of the emanation is long enough to enable a quantity of it to be isolated, before the lecture, in a tube coated internally with a fluorescent compound, and this can be fixed in focus under a lens.

The various exhibits should be labelled, sufficient detail being given to render them interesting without the necessity of the constant repetition of verbal explanations. Before showing the spinthariscopic action of the α rays, one of the mechanical slides, which imitate the scintillating effect, should be shown with the aid of the lantern. These slides consist of two discs, perforated by very small holes, which can be made to rotate in opposite directions; they are wonderfully effective in conveying some idea of the appearance of the beautiful action which they are designed to imitate and, accompanied by a verbal explanation, will

suffice when a view of the spinthariscope is for any reason impossible.

Vacuum tubes containing helium, argon, etc., are very interesting exhibits, and, if the spectra can be shown with a good spectroscope, their beauty cannot fail to be appreciated.

APPENDIX

RADIO-ACTIVITY is an atomic property, depending for its manifestation on the instability of atomic systems, the disintegration of which is marked by the emission of rays. The rays are of three distinct types, known respectively as the α, β, and γ rays.

The "period" of a radio-active element is the time which must elapse before its activity has fallen to one-half of its initial value. The proportion which the number of atoms undergoing disintegration per unit time bears to the total number in any given mass determines the period.

α **rays.**—The α rays consist of particles of atomic dimensions carrying a positive electric charge. At the present time it is uncertain whether this charge is an intrinsic property of the particles, or acquired by ionisation due to impact with matter. As determined by means of the magnetic deflection, the mass of the α particle appears to be rather more than twice the mass of the hydrogen atom, but this value is uncertain, and there is indirect evidence which seems to suggest that the α particle is a helium atom (at. wgt. 4). The real nature of the α particle is thus a matter of doubt. The α particles emitted by the radio-elements and many of their disintegration products have velocities which vary within fairly wide limits, so that each element or active product is distinguished by the ionisation range of its α radiation. The numerical determinations concerning the α particles emitted by radium are :—

Velocity = $2{\cdot}5 \times 10^9$ cms. per second (about 15,000 miles per second).

Ratio $\frac{e}{m} = 6 \times 10^1$.

Mass = 2·5 (according to observations of the magnetic deflection).

Electric charge—positive.

Kinetic energy = $5{\cdot}9 \times 10^{-6}$ ergs.

Power to penetrate solid matter—slight.

The heating effects of radium, or the radio-elements in general, are almost entirely due to the energy of the α rays.

β rays.—The β rays consist of free electrons projected from the active element with exceedingly high velocities, and are identical in nature with the electrons composing the kathode stream of the vacuum tube.

Velocity = $1{\cdot}6 \times 10^{10}$ cms. per second (variable over wide limits and can approach 0·9 velocity of light).

Ratio $\frac{e}{m} = 10^7$.

Mass = $\frac{1}{770}$ of the hydrogen atom (approximately).

Power of penetration—great.

γ rays.—The view most generally held is that the γ rays consist of etheric pulsations set up by the sudden positive accelerations experienced by the electrons at the moment of disintegration of the atomic systems from which they are emitted. This view has recently been challenged by Prof. Bragg, who advances the theory that the γ rays are also particulate but electrically neutral, and therefore not deviable by magnetic or electrostatic forces. This

theory is the outcome of observations of certain phenomena connected with secondary radiation. The question still awaits solution, but the fact that γ radiation does not appear apart from β rays seems in favour of the ether-pulse theory.

THE RADIO-ACTIVE ELEMENTS

Uranium.—Element, slightly radio-active (symbol, Ur.).
Position in periodic law—Group VI., series 12.
Atomic weight = 239.
Period = 5×10^{9} years.
Emits α, β, and γ rays when in radio-active equilibrium.
The uranium series of products as known at present is as follows :—

Uranium, period = 5×10^{9} years; emits α rays.
↓
Ur. X ,, = 22 days ,, β and γ rays.
↓
Ionium ,, = (?) ,, α rays.
↓
Radium ,, = 2000 years ,, α rays.
↓
Etc.

Radium. — Element — highly radio-active — divalent (symbol, Ra.).
Position in periodic law—Group II., series 12.
Atomic weight = 226·5 (chemically determined).
Period = 2000 years.
Emits α, β, and γ rays when in radio-active equilibrium.

Series of disintegration products as follows :—

Radium	period 2000 years;	emits α rays	(ionisation range, 3·5 cms.)
↓			
Emanation (gas)	,, 3·7 days	,, α ,,	(ionisation range, 4·3 cms.)
↓			
Ra. A	,, 3 minutes	,, α ,,	(ionisation range, 4·8 cms.)
↓			
Ra. B	,, 26 minutes	,, β ,,	—
↓			
Ra. C	,, 19 minutes	,, $\alpha, \beta, \& \gamma$ rays	(ionisation range, 7·06 cms.)
↓			
Ra. D	,, 40 years	—	—
↓			
Ra. E	,, 6 days	—	—
↓			
Ra. F	,, 4·5 days	,, β rays	—
↓			
Ra. G (Polonium)	,, 140 days	,, α ,,	(ionisation range, 3·86 cms.)
↓			
(?)			

Thorium.—Element—slightly radio-active (symbol, Th.).

Position in periodic law—Group IV., series 12.

Atomic weight = 232.

Period = 10^{10} years.

Emits α, β, and γ rays when in radio-active equilibrium.

Series of disintegration products as follows :—

Thorium	period 10^{10} years;	emits α rays.	
↓			
Meso-thorium	,, (?)	,, β and γ rays.	
↓			
Radio-thorium	,, 800 days	,, α rays.	
↓			
Th. X	,, 3·7 days	,, α ,,	
↓			

Emanation (gas)	period 54 seconds	emits α rays.
↓		
Th. A	,, 11 hours	—
↓		
Th. B	,, 1 hour	,, α ,,
↓		
Th. C	,, (?)	,, α, β, and γ rays.
↓		
(?)		

Actinium.—Element—radio-active (symbol, Act.).
Position in periodic law—uncertain.
Atomic weight—unknown.
Period—unknown.
Emits α, β, and γ rays when in radio-active equilibrium.
Series of disintegration products as follows:—

Actinium	period (?)	—
↓		
Radio-actinium	,, 19·5 days,	emits α rays.
↓		
Act. X	,, 10 days	,, α ,,
↓		
Emanation (gas)	,, 3·7 seconds	,, α ,,
↓		
Act. A	,, 34 minutes	—
↓		
Act. B	,, 3 minutes	,, α, β, and γ rays.
↓		
(?)		

To the various disintegration products of the radio-active elements the expression "transitional elements" may be justly applied.

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